Summer 2014

Identifying and overcoming the barriers to sustainable construction

Cristin Szydlik

Department: Engineering Management and Systems Engineering

IDENTIFYING AND OVERCOMING THE BARRIERS

TO SUSTAINABLE CONSTRUCTION

by

CRISTIN COLLEEN SZYDLIK

A DISSERTATION

Presented to the Faculty of the Graduate School of the

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY
in
ENGINEERING MANAGEMENT

2014

Approved by
Katie Grantham, Advisor
Stuart W. Baur
Steven Corns
Susan L. Murray
Stephen Raper

ABSTRACT

Sustainable construction has become increasingly more prevalent over the last decade. All federal and most state government buildings are mandated to achieve Leadership in Energy and Environmental Design (LEED) certification (at the silver level at a minimum). Although sustainable construction is increasingly more common, there are still barriers to the successful completion of a sustainable project, specifically with regards to projects achieving LEED certification. There are still holes in the guidance on how to successfully achieve LEED certification. Even though government agencies have mandated LEED certification, the existing barriers are preventing buildings from achieving certification, which can delay the building turnover and contract closeout.

This project seeks to fill the holes in current guidance for achieving LEED certification and provide a construction management process for managers to use in order to successfully complete a LEED project on time, on schedule, and with no impact to quality. This project also seeks to identify the existing barriers to sustainable construction and the construction management processes that can be implemented in order to overcome the barriers. A survey was conducted to identify which management processes were needed with regards to sustainable construction. A focus group and an industrial application were analyzed to determine if the management practices proposed in this research could overcome the barriers to sustainable construction. Based on this study, the existing barriers to sustainable construction were identified as well as management practices to overcome the barriers.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Katie Grantham, for her encouragement, patience, and time throughout this process. She was absolutely essential to the completion of this dissertation. I may be biased, but she is the best advisor a graduate student could ask for.

I would also like to thank Dr. Kevin Burr of Brigham Young University for his guidance, help, and inspiration. His knowledge of the construction industry is vast. I am grateful that he was willing to share it with me.

I would also like to thank Dr. Susan Murray for providing significant guidance and assistance. I would like to acknowledge my committee members, Drs. Stuart Baur, Steven Corns, and Stephen Raper. They all provided insight and guidance that helped me to complete the undertaking.

I would like to profusely thank my parents and my sister for their unconditional support. Every day, I strive to live up to the example they have set for our family.

Finally, I must acknowledge and thank my husband, Brian Szydlik. He is the most supportive, understanding, and loving husband I could ever ask for. I am forever grateful for each moment I get to share with him.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

1.1. MOTIVATION/RATIONALE FOR STUDY

Sustainable construction is not only innovative and forward-looking; it is so prevalent, that the U.S. Army Corps of Engineers recommended the implementation of U.S. Green Building Council's LEED[1] as the Army's green building rating system in 2006 (Napier, 2011). In 2010, the U.S. General Services Administration mandated a LEED Gold Certification as a minimum in all new federal building construction and substantial renovation projects (Beatty, 2010). The government continues to look forward with sustainability in its future with a goal of federal facilities meeting a net-zero usage for water, waste, and energy by 2030. The Executive Office of the Federal Government stated, "As the largest consumer of energy in the U.S. economy, the federal government can and should lead by example when it comes to creating innovative ways to reduce greenhouse gas emissions, increase energy efficiency, conserve water, reduce waste, and use environmentally-responsible products and technologies." (Roulo, 2009). In addition to the federal government's commitment to sustainable construction, there are roughly 180 cities that give LEED builders tax breaks, grants, permitting, and wavers. As of October 2012, there were roughly 2,000 developments, buildings and homes that have received over $500 million in tax breaks nationwide (Frank, 2012).

"Sustainable construction" is called many things and can have many different definitions. The terms green, sustainable, high performance, and even LEED are used to describe the same type of building construction. For the purposes of this project,

[1] Leadership in Energy and Environmental Design

sustainable construction is defined by the U.S. Environmental Protection Agency (EPA) as "the practice of creating structures and using *processes* that are environmentally responsible and resource-efficient throughout a building's lifecycle from siting to design, *construction*, operation, maintenance, renovation, and deconstruction" (Napier, 4).

There are several organizations that have established guidelines for constructing a sustainable project, but the most prevalent and recognized guideline in the U.S. is Leadership in Energy and Environmental Design (LEED). LEED is an internationally recognized green building certification system established by the U.S. Green Building Council (USGBC) in 2000. The USGBC states that the intent of sustainable construction is "to significantly reduce or eliminate the negative impact of buildings on the environment and on the building occupants." The USGBC also goes a step further and identifies the secondary and tertiary effects of sustainable construction as "… also reduces operating costs, enhances building and organizational marketability, potentially increases occupant productivity, and helps create a sustainable community." By the end of 2006, LEED (new construction) had captured over 4% of the total new construction market. By the beginning of 2007, more than 100 new construction projects were register for LEED evaluation (Yudelson, 2007). Since its inception, USGBC has certified over 24,000 buildings (U.S. Green Building Council).

Despite the success of LEED and the U.S. green building movement in general, challenges abound when implementing sustainability principles within the well-entrenched traditional construction industry (Kibert, 2008). There remain barriers to more widespread acceptance of sustainable construction. Such barriers include perception about increased project costs and lack of experience with LEED and/or sustainable techniques and technologies. The increased project costs can manifest itself both in the design and the construction phases of a project. Increased project costs specific to construction include more paperwork, including LEED certification, extra oversight needed to monitor sustainable requirements, and implementing increased design initiatives. Prevalence of conventional thinking and aversion to risk stems from inexperience and deters stakeholders from perusing such project initiatives (Kibert, 2008).

Despite the guidance given for LEED certification from the U.S. Green Building Council, there are still holes in the guidance that need to be filled for a project manager to have the process he or she needs to successfully complete a LEED project. The current guidance as well as the holes that need to be filled are listed in Table 1.1 below and are organized in categories of waste management, materials and resources, indoor air quality, and commission.

Table 1.1 Current Guidance and the Holes that Need to be Filled

Current Practices	**What are the holes in the current practices**
Construction waste management	**Construction waste management**
What does LEED say?	**What is missing?**
Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or comingled. Track and keep a summary log of all construction waste generated by type, the quantities of each type that were diverted and landfilled, and the total percentage of waste diverted from landfill disposal. A project's construction waste management plan should, at a minimum, identify the diversion goals, relevant construction debris and materials to be diverted, implementation protocols, and parties	There is no mention of the construction manager's interaction with the subcontractors. There is no mention of how to make the construction waste management plan efficient or effective. It is essentially a specification with no means or methods.

responsible for implementing the plan (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).	
What does literature say?	
A detailed and comprehensive plan is important to the success of the construction project. There is a need to optimize construction practices to facilitate construction and demolition debris recycling in an economic fashion and to develop the recycling and reuse infrastructure in many area of the United States to support these practices (Haselbach, 2008).	The need for a detailed plan is highlighted without mentioning what the details of the plan actually are.
A properly conceived waste management plan allows a contractor to choose economical alternatives in project waste management. Construction and demolition wastes are generated from a variety of sources on a construction site. In developing a waste management plan, there are choices to consider, including waste minimization, reuse/salvaging/recycling, and landfilling (Showalter, 1999).	The need for a properly conceived waste management plan is highlighted without mentioning what the plan consists of.
When no one is designated to manage waste, the project team would be less keen to discuss waste management during their project meeting, or make their subcontractors aware of any waste policies (Ilozor, 2009).	The need for a designated person to manage waste is highlighted without mentioned what that person should do to make the subcontractors aware of any issues, policies, or procedures regarding waste management.
Materials and resources	**Materials and resources**
What does LEED say?	**What is missing?**
Keep a record and prepare documentation for building reuse, reused or salvaged materials, recycled content (product names, manufacturers' names, costs, percentage postconsumer content, and percentage preconsumer content), regional materials (distances between the project and manufacturer and distance between project and extraction site), rapidly renewable products, and chain-of-custody documentation (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).	There is only a list of data that needs to be recorded. There is no mention of how to procure or install the materials. There is also no mention of how to ensure compliance with the subcontractors actually utilizing the materials.
What does literature say?	**What is missing?**
Improper on-site management and planning can cause delays in passing information on types and sizes of materials and components to be used on the project (Glass, 2008).	There is no information given regarding detail on what proper on-site management is.
All materials are identified as construction submittals; therefore it is the responsibility of the construction manager to ensure that the submittals are timely and in accordance with the LEED criteria for point acceptance (Haselbach, 2009).	There is no mention of how the construction manager should get the submittals from the subcontractors and document how it meets LEED criteria, in a timely manner.
Indoor air quality	**Indoor air quality**

What does LEED say?	What is missing?
Meet the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.12007, Ventilation for Acceptable Indoor Air Quality, prohibit smoking in the building. Develop and implement an IAQ management plan for the construction and preoccupancy phases of the building as follows: During construction, meet or exceed the recommended control measures of SMACNA IAQ Guidelines for Occupied Buildings Under Construction; Protect stored on-site and installed absorptive materials from moisture damage; If permanently installed air handlers are used during construction, filtration media with a minimum efficiency reporting value of 8 must be used at each return air grille; Replace all filtration media immediately prior to occupancy (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).	This is only a list of standards to follow with regard to air ventilation criteria. There is no mention of how to meet the criteria or how to manage the subcontractors to meet the criteria.
What does literature say?	
The nature of air inside the space that affects the health and well-being of building occupants (Haselbach, 2008).	There is no mention of how to manage the project requirements, only a description of what indoor air quality is.
Construction process include methods for storing materials to prevent the introduction of moisture or the accumulation of dust, particulate, and other contamination or nonporous surfaces such as ductwork (Kibert, 2008).	There is no mention of how to manage the subcontractors to meet the criteria or what methods to utilize; it only states that materials should be stored and gives an example of what kind of material should be stored (ductwork).
Commissioning	**Commissioning**
What does LEED say?	**What is missing?**
Designate an individual as the commissioning authority (CxA) to lead, review, and oversee the completion of the commissioning process activities. The CxA must conduct, at a minimum, 1 commissioning design review of the owner's project requirements basis of design, and design documents prior to the mid-construction documents phase and back-check the review comments in the subsequent design submission. The CxA must review contractor submittals applicable to systems being commissioned for compliance with the owner's project requirements and basis of design. The review must be concurrent with the review of the architect or engineer of record and submitted to the design team and the owner (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).	There is no mention of the construction manager, only the commissioning authority (who has no contractual relationship with the subcontractors)
What does literature say?	

During the construction phase the commissioning team works to ensure that equipment, systems and assemblies are properly installed, integrated, and operating in a manner that meets the Owner's project Requirements (New Construction Building Commissioning Best Practices: Building Commissioning Association, 2011).	This is a general overview of what commissioning is; it does not provide any mention of how the construction manager plays a role in the commissioning process.
General contractors, provided they have experience with projects of similar size and complexity, have the scheduling and construction background necessary to supervise a commissioning agent in the quality control manager sense. The general contractor assists with the development and implementation of functional performance testing for all systems. This involves assisting in gathering information (shop drawings, operation and maintenance manuals, and as-built documents) for review by the project team. The general contractor facilitates the commissioning schedule by coordinating activities with owner representatives and subcontractors. Contractors and subcontractors are also responsible for training building operators in the proper operation and maintenance manuals on the equipment that they install (Commissioning for Better Buildings in Oregon, 1997).	There is no mention of how the construction manager should coordinate between the different entities, such as the commissioning agent and the subcontractors. This reference only states that the construction manager is responsible for coordination without mentioning how to do it.

LEED certification has evolved since its inception, to the latest standard referred to as LEED 2009. In LEED 2009, the allocation of points between credits is based on the potential environmental impacts and human benefits of each credit with respect to a set of impact categories. The impacts are the environmental or human effect of the design, *construction*, operation, and maintenance of the building, such as greenhouse gas, emissions, fossil fuel use, toxins and carcinogens, air and water pollutants, and indoor environmental conditions (LEED, 2009).

LEED is broken down into five categories with corresponding points assigned to each credit within the categories: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), and Indoor Environmental Quality (EQ). Projects receive certification levels based on how many credits it achieves:

Certified projects achieve 40-49 points; Silver projects achieve 50-59 points; Gold projects achieve 60-79 points; and Platinum projects receive over 80 points.

This dissertation will focus on reducing such impacts associated with *construction* of a building by maximizing efficiency related to the processes needed to comply with LEED credits related to construction management, hereby referred to as CM credits. These CM credits number 18, with a total of 21 possible points. Table 1.2 summarizes the LEED credits that are the responsibility of the construction manager (USGBC, 2009).

Table 1.2. Construction Management Credits

Credit	**Possible Points**
SS Prerequisite 1 Construction Activity Pollution Prevention	
SS 5.1 Site Development: Protect or Restore Habitat	1
EA Prerequisite 1 Fundamental Commissioning of Building Energy Systems	
EA 3 Enhanced Commissioning[2]	2
MR 2 Construction Waste Management	2
MR 3 Materials Reuse	2
MR 4 Recycled Content	2
MR 5 Regional Materials	2
MR 6 Rapidly Renewable Materials	1
MR 7 Certified Wood	1
IEQ 3.1 Construction IAQ Management Plan – During Construction	1
IEQ 3.2 Construction IAQ Management Plan – Before Occupancy	1
IEQ 4.1 Low-Emitting Materials – Adhesives and Sealants	1
IEQ 4.2 Low-Emitting Materials – Paints and Sealants	1
IEQ 4.3 Low-Emitting Materials – Flooring Systems	1
IEQ 4.4 Low-Emitting Materials – Composite Wood and Agrifiber Products	1

[2] Commissioning is typically the responsibility of an independent Commissioning Agent; however, commissioning occurs during construction and requires coordination with the construction manager.

A LEED certified building requires a minimum of 40 points; construction management comprises nearly half of the points needed. The highest level of certification, platinum, requires 80 points. Even at the most ambitious certification level, construction management affects almost 25% of points needed for certification. The significant construction processes that earn credits, and ultimately produce a sustainable project, include storm water management, construction waste management, material procurement, and indoor air quality.

There are many stakeholders involved throughout the life of a construction project. The work environment and culture of a construction project is unique compared to most working conditions. A typical construction project consists of groups of people, normally from several organizations, that are hired and assigned to a project to build a facility (Oberlender, 2000).

The other main facet of a construction project is the design. Besides owner decisions and input, design accounts for the remaining credits needed to achieve LEED certification. The interaction and communication between stakeholders, specifically the designer and the construction manager becomes increasingly important as a project strives to become sustainable and meet its LEED certification goals. The contract delivery method highly influences project interface between stakeholders, and management of the subcontractors by the construction manager. Contemporary construction delivery systems in the United States fall into three major categories: design-bid-build, construction management-at-risk, and design-build (Kibert, 2008).

This dissertation will focus on the differences between design-bid-build and design-build, and how they relate to sustainable construction, as defined below in Table 1.3 (Burr, 2001):

Table 1.3 Contract Delivery Methods

Design-Bid-Build (D-B-B): a project delivery system method in which the Purchasing agency (Owner) sequentially awards separate contracts, the first for architectural and engineering services to design the project and the second for construction of the project according to design.	Design-Build (D-B): a performance based project delivery mthod in which the Purchasing agency (Owner) enters into a single contract for design and construction of a facility.

In a typical design-bid-build contract, the design is completed independently of the construction. "We give construction professionals (who typically are not involved in the design process) four weeks to bid on these [design] documents…Not only are we giving contractors only a week or two to understand hundreds of thousands of hours' worth of information, but we are also asking them to put a price on that understanding and, further, to commit contractually to meeting that price." (Reed, 2009). Also included in that limited amount of time, is the initial subcontractor coordination, or lack thereof, depending on the time frame. This sets the path of attempting to communicate the sustainable goals of the project with key entities that have even *less* of an understanding of the project.

1.2. PROBLEM STATEMENT AND OBJECTIVES/PURPOSE STATEMENT

1.2.1. Problem Statement. Through detailed construction management processes (focused on LEED criteria), it is possible to overcome any remaining barriers to sustainable construction.

1.2.2. Goal. The goal of this dissertation is to determine if detailed construction management processes, including waste management, material procurement, indoor air quality, and commissioning can be applied to the bid and build phases of a sustainable construction, design-bid-build procurement project to obtain LEED certification to overcome the existing barriers to sustainable construction, without impacting cost, schedule, or quality. In order to meet this goal, this research will identify the following objectives.

1.2.3. Objectives. The objectives of this dissertation are:

a. Identify any remaining barriers to sustainable construction.

b. Identify a process for managing construction of a sustainable project¸ consisting of construction waste management, material and resource management, indoor air quality during construction and before installation, and commissioning.

1.3. SCOPE

As previously stated, the EPA defines sustainable construction as “the practice of creating structures and using *processes* that are environmentally responsible and resource-efficient throughout a building’s lifecycle from siting to design, *construction*, operation, maintenance, renovation, and deconstruction” (Napier, 4). A building’s lifecycle is a long and complex existence, comprised of many decision points and extensive cost analysis. Therefore, this study only addresses the *processes* specific to *construction* and how to make such processes effective and efficient on a sustainable project. This study is specific to a higher education facility; the work will not focus on a complete analysis of all types of construction projects.

1.4. HOW TO USE THIS DOCUMENT

Throughout this document, each section will begin with an overview containing a road map for the section and a list of new information within the section. A quick read of the first sub-section will tell you specifically the contents of the section. At the end of each section, a summary sub-section will highlight the key points presented.

Section 2 discusses the background of construction management as it pertains to sustainable projects, and specifically LEED points and certification. Section 2 will also discuss barriers to sustainable construction, higher education sustainable efforts and contract delivery methods.

Section 3 presents the methodology for determining what construction management processes can overcome barriers to sustainable construction. Section 4 presents the findings from a focus group and survey on how the existing barriers to sustainable construction were determined and management processes that can be utilized to address the barriers. Section 5 will detail the proposed solutions to overcome the existing barriers. Section 6 will present the findings from the industrial application of the implementation of the proposed solutions. This section includes the original work of this dissertation; a construction management method as it was applied to a LEED construction project, without increasing cost or time, or sacrificing quality. Section 7 details the conclusions, recommendations, implications from the findings, and further research topics.

1.5. SUMMARY

This section introduced the importance of sustainable construction and the challenges that face the construction manager when overseeing a project attempting LEED certification. The rationale for study, hypothesis, and scope of the research were presented in detail. The upcoming sections will continue to detail, though a focused analysis of the findings produced from a focus group and industrial application, the best and most effective practices for construction management on a sustainable construction project.

2. BACKGROUND

2.1. INTRODUCTION

This sections will provide background information on several key concepts related to the research methodology presented in Section 3. Through a review of literature, this section introduces significant ideas and concepts relevant to sustainable construction. This review is divided into sections that comprise the major areas of research, important to the foundation of this study:

1. Defining Sustainable Construction
2. Sustainability Efforts in Construction
3. Leadership in Energy and Environmental Design
4. Sustainability in Higher Education Construction
5. Contract Delivery Methods

2.2. DEFINING SUSTAINABLE CONSTRUCTION

The sustainable development movement has been evolving worldwide for quite some time, causing significant changes in building delivery systems in a relatively short period of time (Kibert, 2008, Essa, 2008, Abidin, 2005). A widely accepted worldwide definition of sustainable construction is"development that meets the needs of the present without compromising the ability of future generations to meet their own needs", formally defined by the Brundtland Commission in 1987 (Haselbach, 2008).

The Counseil International du Batiment (CIB), an international construction research organization, listed seven core principles to sustainable construction (Kibert, 2008):

<u>The Principles of Sustainable Construction</u>

1. Reduce: Reduce resource consumption
2. Reuse: Reuse resources
3. Recycle: Use recyclable resources
4. Nature: Protect nature
5. Toxics: Eliminate toxics
6. Economics: Apply life-cycle costing
7. Quality: Focus on quality

These principles of sustainable construction as it apply across the entire life cycle of construction, from planning to disposal (deconstruction). These principles also apply to the resources needed to create and operate the built environment during its entire life cycle; land, materials, water, energy, and ecosystems (Kibert, 2008). These principles pertain to both the resources needed to create a building and the phases of construction. The construction phases, construction resources, and the principles of sustainable construction are all intertwined and cannot be considered individually (Kibert, 2008).

Taking the above mentioned Brundtland Commission definition and the CIB principles of sustainable construction into account, in laymen's terms sustainable construction can be described as the way things are used, how they are communicated to the world, and the way they are produced. Thus, the CIB principles depict a broad, yet fundamental conceptual understanding of sustainable construction. In order for such principles to be implemented on a construction project, they must be dissected into more specific design and construction criteria. Some of the elements of sustainable construction design practice include (Yudelson, 2007):

- High levels of resource efficiency overall, including transportation and energy use in building materials, construction and building operations

- Energy-efficient building systems
- Renewable energy use
- Water conservation and graywater use
- Habitat preservation and restoration
- Use of natural energies for building heating and cooling
- Rainwater capture, reuse and recycling
- Natural stormwater management
- Use of recycled-content, non-toxic, salvaged and local materials
- Healthy and productive indoor environments for people
- Durability of building materials and designs
- Flexibility for building uses to change over time
- Access to alternative transit modes

Most existing green buildings feature incremental improvement over, rather than radical departure from, traditional construction methods. Nonetheless, this process of gradual incorporation of sustainability principles continues to advance the industry's evolution toward the ultimate goal of achieving complete sustainability throughout all phases of the built environment's life-cycle (Kibert, 2008).

Table 2.1 below illustrates the dynamic of how the CIB Principles of Sustainable Construction are broken down from principles into elements and finally into specific examples of sustainable construction. As the principles, elements and examples are cross-referenced, it becomes apparent that many facets of sustainable construction are intertwined and interrelated (Kibert, 2008):

Table 2.1 Principles, Elements and Examples of Sustainable Construction

CIB Principles of Sustainable Construction	Elements of Sustainable Construction	Examples of Sustainable Construction Criteria
Reduce	Use of natural energies for building heating and cooling Access to alternative transit modes High levels of resource efficiency overall, including transportation and energy use in building materials, construction and building operations Renewable energy use; Energy-efficient building systems Water conservation and graywater use	Treat and reclaim wastewater for onsite use Reclaim and reuse rainwater/graywater Natural ventilation; operable window; low-pressure distributed ventilation
Reuse	Rainwater capture, reuse and recycling Water conservation and graywater use Renewable energy use	Urban infill; adaptive reuse of building stock; Treat and reclaim wastewater for onsite use; Reclaim and reuse rainwater/graywater
Recycle	Rainwater capture, reuse and recycling; Use of recycled-content, non-toxic, salvaged and local materials	Life-cycle assessment of materials; Use recycled materials such as fly ash for concrete
Nature	Habitat preservation and restoration; Natural stormwater management Renewable energy use	Detain, retain, recharge, re-use stormwater onsite
Toxics	Healthy and productive indoor environments for people; Use of recycled-content, non-toxic, salvaged and local materials	Life-cycle assessment of materials; Use recycled materials such as fly ash for concrete
Economics	Flexibility for building uses to change over time Use of natural energies for building heating and cooling Renewable energy use Energy-efficient building systems	Life-cycle cost analysis; triple-bottom-line thinking; Life-cycle assessment of materials; Use recycled materials such as fly ash for concrete; Design whole systems; Expanded temperature band; Look at health and productivity of the workforce
Quality	Durability of building materials and designs	Life-cycle assessment of materials; Use recycled materials such as fly ash for concrete; Design whole systems; Expanded temperature band; Look at health and productivity of the workforce

Table 2.2 below assists in conceptualizing how sustainable principles are put into practice in building projects by contrasting them with conventional criteria. The sustainable engineering criteria encompass all facets of a building, from the HVAC[3], plumbing, electrical, water, building envelope, and finishes (Yudelson, 2009).

Table 2.2. Conventional vs. Sustainable Engineering

Category	**Conventional Engineering**	**Sustainable/High-performance Engineering**
Buildings	Suburban greenfields; New buildings preferred	Urban infill; Adaptive reuse of building stock
Energy Use	Meet energy code; Reduce energy use vs. code	Exceed code by 505; Reduce absolute energy use; Develop new systems and methods; Use on site power such as co-generation
Economics	First cost is major driver; look only at project economics	Life-cycle cost analysis; Triple-bottom-line thinking
Ventilation	Forced ventilation; Sealed windows; high-pressure central systems	Natural ventilation; operable window; Low-pressure distributed ventilation
Climate control	Design with components; Narrow temperature band; Consider only HVAC system economics	Design whole systems; Expanded temperature band; Look at health and productivity of the workforce
Water use	Specify efficient fixtures	Reclaim and reuse rainwater/graywater
Stormwater	Convey off site to treatment plant	Detain, retain, recharge, re-use on site
Wastewater	Convey off site to treatment plant	Treat and reclaim for onsite use
Materials selection	Environmental effects not considered	Life-cycle assessment of materials; Use recycled materials such as fly ash for concrete

[3] Heating, Ventilation & Air Conditioning

2.3. SUSTAINABILITY EFFORTS IN CONSTRUCTION

In “Green Building A to Z”, the author wrote that “Most of the buildings in this country in the year 2035 have yet to be built or renovated. Between tearing down many older buildings, renovating some that are structurally sound or architecturally significant and building new structures, most of our building stock can be influenced by actions we take today to green the built environment” (Yudelson, 2007). Yudelson continued by quoting architect Edward Mazria.

> *In the year 2035, three-quarters of the built environment in the US will be either new or renovated (representing more than 300 billion square feet of construction). This transformation over the next 30 years represent a historic opportunity for the architecture and building community to reverse the most significant crisis of modern time, climate change.*

In 2009, a study was conducted by the Liverpool John Moores University with the purpose of understanding what factors best promote or prevent sustainable construction practices and establish the consistency of how sustainability is measured (Pitt, 2009). The study determined that the main drivers for sustainable construction are financial incentives and building regulations. Affordability was seen as the biggest barrier to sustainable construction, indicating that sustainable construction is more expensive to execute compared to standard practices (Pitt, 2009). The drivers and barriers of sustainable construction for developers are summarized below in Table 2.3.

Table 2.3. Drivers and Barriers to Sustainable Construction

Drivers	Barriers
Client awareness	Affordability
Building regulations	Building regulations
Client demand	Lack of client awareness
Financial incentives	Lack of business case understanding
Investment	Lack of client demand
Labeling/Measuring	Lack of proven alternative technologies
Planning policy	Lack of one labeling/measuring standard
Taxes	Planning policy

The research conducted by the Liverpool John Moores University is useful in identifying factors that make sustainable construction appealing and the barriers that still remain to diminish higher demand for sustainable construction. The research was limited because it relied on survey responses of 83 professionals within the United Kingdom. The study did not address construction in the United States, which has one main governing body for sustainable construction certification (LEED).

2.3.1. Construction Waste Management. Construction consumes up to 60% of raw materials used in the US economy, and about 136 million tons of building-related construction and demolition waste is generated each year, out of which only 20% is recycled. Construction waste consists mainly of lumber (35%); drywall (15%), masonry materials (12%); and cardboard (10%) (Ilozor, 2009). Construction waste is effectively generated throughout the project from inception to completion. The origins and causes of waste are listed in Table 2.4 below (Glass, 2008).

Table 2.4 Origins and Causes of Construction Waste

Origins of Waste	**Causes of Waste**
Contractual	Errors in contract documents
Design	Design Changes
	Design and detailing complexity
	Design and construction detail errors
	Unclear/unsuitable specification
	Poor coordination and communication (late information, last minute cline requirements, slow drawing revision and distribution)
Procurement	Ordering error (i.e. ordering items not in compliance with specification)
	Supplier errors
Transportation	Damage during transportation
	Insufficient protection during unloading
	Insufficient methods of unloading
On-site Management and Planning	Delays in passing information on types and sizes of materials and components to be used

A study was conducted in 2009 to identify and assess factors that can improve waste management on a construction project. The findings were based on 57 survey responses to construction managers with average work experience of approximately nine years (Cha, 2009). Table 2.5 summarizes the methods for improving waste management performance (Cha, 2009).

Table 2.5 Methods for Improving Waste Management Performance

Category	Method
Manpower	Commitment of contractor’s representative at site
	Appointment of laborers solely for wastes disposal
	Cooperation of subcontractors
	Education of the contractor’s staff (engineers)
	Education of subcontractor’s staff (laborers)
	Preventing waste of materials by laborers
Materials and Equipment	Collecting packed materials back by suppliers
	Minimizing rework on a construction phase
	Design and construction using standardized materials
	Prefabrication of materials
	Use of recycled materials
	Preventing easily fragile materials from being used
	Minimizing loss of materials during carrying and storing
Construction Method	Setting up separated bins by waste type
	Sorting out individual waste by type from mixed wastes
	Designate a place for storing wastes in an early stage of construction
	Storing wastes at an easily accessible areas
	Preventing the ordering of excess materials
	Providing bins for collecting wastes for each subcontractor
	Installing equipment for recycling in a site
	Preventing mixing wastes with soil
	Installing an information board to notice categories for separating wastes
Management Practices	Contractual clauses for a subcontractor in dealing with wastes
	Positive incentive for decreasing or recycling by subcontractors
	Keeping a record about waste management (amount, kinds, etc)
	Shortening a period of collecting wastes in a site
	Contractual clauses about the methods for a waste disposal agency to treat wastes
	Establishing a waste management plan in an early state of construction
	Checklist on executing detailed waste management plan

There is a need to optimize construction practices to facilitate construction and demolition debris recycling in an economic fashion and to develop the recycling and reuse infrastructure in many areas of the United States to support these practices (Haselbach, 2008, Yuan, 2011, Hwang, 2011). Construction waste management is a credit under LEED. A properly conceived waste management plan allows a contractor to choose economical alternatives in project waste management. Construction and demolition wastes are generated from a variety of sources on a construction site. In developing a waste management plan, there are choices to consider, including waste minimization, reuse/salvaging/recycling, and landfilling (Showalter, 1999).

One of the main factors in implementing a waste management plan is defining waste disposal responsibilities of all parties involved. Owners may include explicit language in the proposal that stipulates the major requirements for waste management and any waste reduction.[4] A general contraction may stimulate that a subcontractor be responsible for developing a waste management plan, or implementing and adhering to a plan established by the general contractor. A case study conducted by Eastern Michigan University in 2009 concluded that commercial (followed closely by residential) construction *will* waste concrete during construction without the existence of a waste management plan. The study continued to point out that when no one is designated to manage waste, the project team would be less keen to discuss waste management during their project meeting, or make their subcontractors aware of any waste policies (Ilozor, 2009). The study was limited to construction projects in Michigan and it did not address LEED certification of the projects.

The ease and cost of compliance with this credit varies greatly by location (Matthiessen, 2007). While it is increasingly common for contractors to hire a waste

[4] An owner may also stipulate that the project achieves LEED certification and require the Materials & Resource Credit 2.2 Construction Waste Management. LEED credits will be discussed in detail Section 2.4 Leadership in Energy and Environmental Design.

hauler to take commingled waste[5] and sort it off-site, many contractors have found that they can actually save costs by sorting waste onsite, if the space is available (Matthiessen, 2007). Any additional project cost produced because of construction waste management can be due to two factors; direct cost of waste management and documentation costs. The direct costs arise from developing procedures, training, recycling charges, and dump fees (Matthiessen, 2007). The documentation costs occur if the project wishes to demonstrate compliance with the LEED credit.

An additional, although harder to measure, cost impact of waste management is the impact on bidders. In the 2007 Davis Langdon[6] *Cost of Green Revisited Study* stated that in periods of high construction demand and limited competition, inexperienced bidders may view these requirements as unduly onerous, and as a result decline to bid, or bid high to cover what they perceive as the risk. The study continues that this can be mitigated to some degree through bidder outreach and training, but the cost can, nevertheless, be significant in certain locations at periods of local competition. Where the contractor can be engaged during the design process, the costs associated with this point can be reduced or eliminated (Matthiessen, 2007).

2.3.2. Materials and Resources. Each sustainable project has to place some emphasis on appropriate selection of materials (Yudelson, 2009). Examples of sustainable materials include locally sourced, recycled content, rapidly renewable, salvaged, and volatile organic compound (VOC) content within the materials.

---

[5] Comingled waste is multiple types of waste collected in a single dumpster and sorted offsite at a recycling center.
[6] Davis Langdon is a global construction consultant firm. In 2008, Davis Langdon received the USGBC's Leadership Award for its research work in sustainability.

Locally sourced materials must have been extracted, harvested and processed within a certain radius (USGBC defines with radius as 500 miles). Examples of materials that could come from just about any locality without traveling long distances are compost and mulch, concrete storm drains, masonry, pavers and hardscape materials, wheatboard panels, most wood products, and cellulose insulation (Yudelson, 2007).

Recycled content refers to the percent of the total value of the building material that is made from recycled material. Recycled-content materials encourage the development of a local and regional economy that values recycling and that creates new materials with the same performance characteristics (Yudelson, 2007). Recycled content is measured as post-consumer or pre-consumer. Post-consumer material is defined as waste material generated by households, commercial entities, industrial and institutional facilities in their role as end-user of the product, which can no longer be used for its intended purpose. Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).[7] Examples of recycled content materials include fly ash in concrete, acoustic ceiling tile, drywall with recycled paper facing, carpets made from recycled plastics or recycled fibers, and ceramic tile from recycled glass (Yudelson, 2007).

Rapidly renewable materials generally include anything that can be grown and harvested in less than ten years, such as agricultural panel boards from wheat, rice straw, sunflower seeds and sorghum stalks and used for cabinetry and wainscoting, interior

---

[7] Reutilization of materials (i.e., rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it) is excluded (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).

doors, subflooring and plywood; cork and bamboo for flooring, linoleum floor and wool rugs (Yudelson, 2007). Salvaged materials are reused building materials or products that reduce the demand for virgin materials and reduce waste, thereby lessening impacts associated with the extraction and processing of virgin resources (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).

VOCs are an entire class of carbon-based chemicals that give off vapors at normal room temperatures. Thousands of products emit VOCs, including paints and lacquers, paint strippers, adhesives and sealants, carpets and carpet backing, cleaning supplies, pesticides, building materials and furnishings, office equipment, graphics and craft materials, and permanent markers (Yudelson, 2007). High VOC levels are often found in general construction adhesves, flooring and fire-stopping adhesives, caulking, duct sealants and plumbing adhesives. There are also aerosol adhesives, carpet pad adhesives and ceramic tile adhesives with high VOC levels (Yudelson, 2007).

There are three priorities in selecting building materials for a project (Kibert, 2008):

1. As with energy and water resources, the primary emphasis should be on reducing the quantity of materials needed for construction
2. Reuse materials and products from existing buildings through a process call deconstruction.[8]
3. Use products and materials that contain recycled content and that are themselves recyclable or to use products and materials made from renewable resources.

Project designers and product specifiers are often concerned with issues other than the environmental attributes of a product, including performance, cleanability, and durability.

[8] Deconstruction is the whole or partial dismantling of existing buildings for the purpose of recovering components for reuse (Kibert, 2008).

As they acquire more experience with new types of sustainable products, many of these concerns gradually disappear (Yudelson, 2007). Project teams often find it useful to construct a spreadsheet matrix listing materials against the environmental criteria being considered so that materials options can be compared in a simple format (Reed, 2008).

The Davis Langdon *Cost of Green Revisited* Study addressed the cost concerns of sustainable materials and resources (Matthiessen, 2007) . The study concluded that recycled content is not difficult for most projects, up to a certain threshold; however, if the project has a goal of over 20% (by value) of recycled content, there will need to be a concentrated effort to identify high recycled content materials to replace more standard products. Regional and rapidly renewable materials present challenges to projects because it can be difficult to find sufficient suitable materials to qualify as sustainable materials. There are additional documentation requirements should the owner wish to demonstrate compliance with LEED criteria related to sustainable materials and resources (Matthiessen, 2007).

2.3.3. General Construction Management Practices. Construction project management is defined as the art and science of coordinating people, equipment, materials, money, and schedules to complete a specified project on time and within approved cost. Project management often involves organizing and working to identify problems and determine solutions to problems (Oberlender, 2000). Key concepts of project management include (Oberlender, 2000):

1. Establish a work breakdown structure that divides the project into definable and measurable units of work; Develop a project schedule that provides logical sequencing of the work required to complete the job
2. Establish a project organizational chart that shows authority and responsibilities for all team members

3. Emphasize that quality is a must, because if it does not work it is worthless, regardless of cost or how fast it is completed
4. Budget all tasks; any work worth doing should have compensation
5. Document all work, because what may seem irrelevant at one point in time may later be very significant

The key concepts of project management are implemented by the construction manager, or contractors, who have the expertise to translate designs into finished buildings; often, they are instrumental in suggesting better ways to accomplish a goal that the design team did not consider. Early involvement of general contractors is vital to integrating design efforts; they can offer early pricing of design alternatives and consult on the constructability of new approaches (Yudelson, 2009). The construction phase of a project is important because the quality of the completed project is highly dependent on the workmanship and management of construction. A majority of the total project budget and schedule is expended during construction (Oberlender, 2000). In sustainable construction, contractors are specifically tasked with pollution prevention, eliminating runoff of sediment from construction sites through such practices as silt fencing, seeding and mulching, sediment traps and basins, along with earthen dikes (Yudelson, 2007). Table 2.6 lists the difference between conventional and sustainable construction (Yudelson, 2007).

Table 2.6 Sustainable Approach to Construction versus Conventional Construction

Project Process	Traditional Construction	Sustainable Construction
Project manager selection	Select an in-house manager or hire one to serve as the project manager.	Hire an experienced sustainable building consultant/project manager who is familiar with the product type and market and has exposure to all phases of sustainable construction; a LEED accredited professional is optimal.
Initial budget and schedule	Budgets are typically developed by an architect based on a formula or unit costs, which can vary as much as 15% from actual costs.	Complete preconstruction estimates with input from the builder, project manager, architect, and real estate consultant. Estimating costs associated with specialized areas like sustainable building products require experience. The budget may also include an emphasis on life cycle costing, shifting focus from short-term return on investment to long-term gains from operational savings.
Design team selection	Select the architect or general contractor depending on the type of contract. All consultant report to the architect or general contractor.	Usually, the core design team has participated in the planning and design process, construction documents can be developed more efficiently and with little design modifications.
Construction document development	Although the design is finalized by this time, often sustainable initiatives are considered, causing rework.	Because the integrated team has participated in the planning and design process, construction documents can be developed more efficiently and with little design modifications.
Construction	Weekly site inspections are typically reported by architect or builder. There is little cross-communication among the site workforce, including subcontractors.	Launch construction with kickoff meeting that includes a sustainable education competent for on-site construction personnel; monthly on-site meetings are required by entire site workforce and include periodic education and training sessions on sustainable building. Sustainability requirements are reviewed with each subcontractor prior to commencing work.
LEED Certification	Typically not applicable	The ongoing efforts of the project manager, coupled with the benefits of an integrated team and specialized technology, can make compiling and submitting documentation more efficient.
Occupancy and operations	Minimal testing is performed before the building is turned over for operation	Building commissioning is an essential setup in ensuring the building systems function as intended and set forth in the project criteria. The commissioning authority has been hired from the onset and understands the owner’s goals.

Building commissioning is the process of ensuring that building systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs (Elzarka, 2009). The goal of commissioning is to test all energy-using and life-safety systems in actual building operation and to work out all the kinks before occupancy (Yudelson, 2007). The Building Commissioning Association defined the basic purpose of commissioning as providing documented confirmation that building systems function in compliance with criteria set forth in the project documents to satisfy the owner's operational needs (BCA, 2011). The LEED rating system requires a basic commissioning process as a prerequisite for building certification. LEED also awards an additional credit point for a more enhanced commissioning process (Elzarka, 2009).

Successful construction phase commissioning is a well-coordinated quality assurance process that encompasses installation, start-up, functional testing and training. Commissioning ideally begins during the pre-design phase of a building project and continues through the design, construction, acceptance, and occupancy and operations phases of the building. During the construction phase, the commissioning team works to ensure that equipment, systems and assemblies are properly installed, integrated, and operating in a manner that meets the Owner's Project Requirements (OPR) (New Construction Building Commissioning Best Practices: Building Commissioning Association, 2011). During the construction phase, the commissioning team should consist of owner's representation, commissioning, design team, construction management representative, contractors, building occupant, personnel responsible for the building's operation and maintenance (New Construction Building Commissioning Best Practices: Building Commissioning Association, 2011).

General contractors, provided they have experience with projects of similar size and complexity, have the scheduling and construction background necessary to supervise a commissioning agent in the quality control manager sense. The general contractor assists with the development and implementation of functional performance testing for all systems. This involves assisting in gathering information (shop drawings, operation and maintenance manuals, and as-built documents) for review by the project team. The general contractor facilitates the commissioning schedule by coordinating activities with owner representatives and subcontractors. Contractors and subcontractors are also responsible for training building operators in the proper operation and maintenance manuals on the equipment that they install (Commissioning for Better Buildings in Oregon, 1997). The participation of both the contractor and the commissioning agent during the design phase creates a project team with experience in design, construction, and operation that is capable of using integrated design techniques to improve both the constructability and operability of the new building (Elzarka, 2009).

The benefits of commissioning a building include (Oregon Office of Energy, Haselbach, 2008):

- Energy savings/Reduced energy use
- Lower operation costs
- Fewer system deficiencies at building turnover/Reduced contractor callbacks
- Better building documentation
- Improved indoor air quality, occupant comfort and productivity
- Decreased potential for liability related to indoor air quality
- Reduced operation and maintenance and equipment replacement costs
- Verification that the systems perform in accordance with the owner’s project requirements

There are additional construction costs arising from the additional work required of the contractor to support the commissioning process and the corrective work required as a result of the commissioning (Matthiessen, 2007). There are both short and long term benefits that commissioning provides to a building. In the short term, it can help the project team develop an efficient design, and in conjunction with design modeling, serve to reduce overall design and construction time (Matthiessen, 2007). Long term benefits include valuable performance benchmarks, acceptance criteria and a baseline for the future operation and ongoing commissioning, operation and maintenance of the facility (New Construction Building Commissioning Best Practices: Building Commissioning Association, 2011).

Indoor air quality (IAQ) is the nature of air inside the space that affects the health and well-being of building occupants (Haselbach, 2008). Kibert highlighted the best practices for indoor air quality:

Best Practices for IAQ Concepts for Sustainable Buildings

1. Relationships between indoor air pollution sources, ventilation, and concentrations
2. Simple dose-response basis for health effects: “the dose makes the poison”
3. Overall design consideration of IAQ: from cradle to grave
4. Source identification
5. Source control options and strategies
6. Ventilation system design and operation
7. Material selection and specification
8. Construction procedures

The first six best IAQ practice concepts are preparatory to the actual consideration of how to handle the sources of pollution. Potential air pollution sources are numerous and varied: outdoor sources such as water and pesticides; emissions from building materials, especially finishes such as paint and carpeting, but also including adhesives, glues, and acoustic materials; occupant activities; and HVAC (Kibert, 2008). The last two best practices are construction related. The level of construction materials emissions will be a function of the type and quantity of materials that will be used in a project. Construction process include methods for storing materials to prevent the introduction of moisture or the accumulation of dust, particulate, and other contamination or nonporous surfaces such as ductwork (Kibert, 2008).

Subcontracting is a key characteristic of construction. For up to 90% of the total value of a construction project, subcontractors supply labor and material and transform order-related drawings and specifications into physical components of the facility (Hartmann, 2010). Charles Kibert goes as far as stating “perhaps the most important group in a building construction project is the subcontractors” (Kibert, 2008). The general contractor or construction manager organizes and orchestrates a diverse group of subcontractors to produce the building. For a sustainable construction project to meet its objectives, the subcontractors must be made aware of how the building project differs from a conventional construction project (Kibert, 2008, Robinson, 2005).

2.4. BARRIERS RELATED TO SUSTAINABLE CONSTRUCTION

Despite the success of LEED and the U.S. green building movement in general, challenges abound when implementing sustainability principles within the well-entrenched traditional construction industry. Although proponents of green buildings have argued that whole-system thinking must underlie the design phase of this new class of buildings, conventional building design and procurement processes are very difficult to change the mindset within the construction industry. Below are the major barriers to sustainable construction (Kibert, 2008):

1. Financial Disincentives
    a. Lack of life cycle cost analysis and use
    b. Real and perceived higher first costs
    c. Budget separation between capital and operating costs
    d. Security and sustainability perceived as trade-offs
    e. Inadequate funding for public school facilities
2. Insufficient Research
    a. Inadequate research funding
    b. Insufficient research on indoor environments, productivity, and health
    c. Multiple research jurisdictions
3. Lack of awareness
    a. Prevalence of conventional thinking
    b. Aversion to perceived risk

These barriers can be overcome, or mitigated by the following trends in sustainable construction (Kibert, 2008).

1. Rapid penetration of the LEED green building rating system and growth of USGBC membership
2. Strong federal leadership
3. Public and private incentives
4. Expansion of state and local green building programs
5. Industry professionals taking action to educate members and integrate best practices
6. Corporate America capitalizing on green building benefits
7. Advances in green building technology

One of the greatest risks of sustainable construction is cost. The most common reason cited in studies for not incorporating green elements into building designs is the increase in first cost (Morris, 2007). The additional costs, and those associated with green building compliance and certification, often require owners to add a separate line item to the project budget. The danger is that during the course of construction management, when costs must be brought under control, the sustainability line item is one of the first to be "value-engineered" out of the project (Kibert, 2008).

A commonly noted challenge in construction projects is lack of effective communication among various technical experts who tend to use their own tools and industry standards for making decisions and tracking information. Architects, engineers, and builders tend to be highly specialized and deliver services in technical isolation (Robichaud, 2011). Communication will be improved if all trades work together as opposed to the "silo" effect where subcontractors only concern themselves with their own scope and little to no collaboration and coordination with the other trades (Robichaud, 2011). Robichaud continues to discuss mitigation to such risks by stating that the LEED program bridges both the technology and the communication gap that can occur on a sustainable construction project. A LEED project will include more upfront planning for all parities to be successful. LEED is not solely meant for better communication, but it has that affect (Robichaud, 2011). Davis Langdon published a study in 2007 that stated:

> *Sustainable materials and systems are becoming more affordable, sustainable design elements are becoming widely accepted in the mainstream of project design, and building owners and tenants are beginning to demand and value those features. It is important to note, however, that advanced sustainable features can add significantly to the cost of a project and these must be valued independently to ensure that they are cost and/or environmentally friendly* (Morris, 2007).

The cost for incorporating sustainable design elements will depend greatly on a wide range of factors, including (Morris, 2007)

- Building type
- Project location
- Local climate
- Site conditions
- Familiarity of the project team with sustainable design

The 2007 report "What Does Green Really Cost" stated that integrating the construction team into the project team[9] is also highly desirable. Many sustainable design features can be defeated or diminished by poor construction practices (Morris, 2007). The Davis Langdon Study concluded that sustainability goals, strategies, and budgets can readily be established and integrated during the project management phase in exactly the same way any other project goals, strategies, and budgets can be established: through the use of good planning processes (Morris, 2007).

Davis Langdon conducted another study in 2007 with the purpose of analyzing the cost of incorporating sustainable design features into projects (Matthiessen, 2007). The study concluded with two findings key to this research:

1. Many projects are achieving LEED within their budgets and in the same cost range as non-LEED projects.
2. The idea that green is an added feature continues to be a problem.

The study also concluded that many project teams are building green buildings with little or no added cost, and with budgets well within the cost range of non-green buildings with similar programs. In many areas of the country, the contracting community has

[9] Project teams are made up of all the participants who are necessary to complete the project, including in-house personnel and outside consultants. The construction team is a component of the overall project team, consisting of groups of people, normally from several organizations, that are hired and assigned to build the facility (Oberlender, 2000).

embraced sustainable design, and no longer sees sustainable design requirements as additional burdens to be priced in their bids. This study compared construction costs of buildings where LEED certification was a primary goal to similar buildings where LEED was not considered during design (Matthiessen, 2007). The study concluded that there is no significant difference in the average cost of LEED seeking and non-LEED seeking buildings in both academic and laboratory buildings, on a cost per square foot basis (Mattiessen, 2007).

The exception to this finding is on project with less experienced project teams. On such projects, there continues to be a conception that sustainable features are something that gets added to the project; therefore, there is an additional cost (Matthieseen, 2007). There is also the cost of documentation that remains a concern for some project teams and contractors, although as teams become accustomed to the requirements, the concern is abating somewhat (Matthiessen, 2007).

2.5. LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN

As initially stated in Section 1, the EPA defined sustainable construction as “the practice of creating structures and using *processes* that are environmentally responsible and resource-efficient throughout a building’s lifecycle from siting to design, *construction*, operation, maintenance, renovation, and deconstruction” (Napier, 4). This definition of sustainable construction is important because it is the basis for U.S. Green Building Council’s definition in LEED 2009.

S. Rick Fedrizzi, Founding Chair of U.S. Green Building Council, stated that it is clear what we need to do to build sustainably (Reed, 2009):

> *Build so that we use less energy and less water and use fewer finite resources or figure out how to use more recycled resources. Build so that our choices deliver healthier solutions that respect the building's occupants, not compromise them. Build with an eye to future savings not first cost. Build smarter. Build so our children have a future).*

Leadership in Energy and Environmental Design, LEED, is a sustainable rating system developed by the U.S. Green Building Council (Potbhare, 2009, Presley, 2010). LEED is a tool that functions to identify in a very clear format the environmental issues that need to be addressed (Reed, 2009).

The USGBC was formed in 1993 and as of 2010, represents more than 14,000 members[10] including federal, state, and local government agencies; colleges and universities, environmental NGOs[11]; product manufacturers; trade associations; architects, engineers and builders, and a myriad of other disciplines and professions engaged in the building industry (Yudelson, 2009). The mission of USGBC is:

> *To transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life.*

The vision of USGBC is *Buildings and communities will regenerate and sustain the health and vitality of all life within a generation.* Since the USGBC was formed in 1993, it has defined, and redefined the criteria for LEED rating system. From 1993 to 1998, a USGBC task force diligently developed a rating system to evaluate a building's resource efficiency and environmental impacts (Kibert, 2008). The initial pilot program, LEED

---

[10] As of November 2011 (U. S. Green Building Council)
[11] Non-governmental organization

Version 1.0, was launched in 1998. After extensive modifications, LEED Green Building Rating System Version 2.0 was released in March 2000; followed by LEED Version 2.1 in 2002, and LEED Version 2.2 in 2005 (USGBC 2009, xi). As LEED as evolved, it has developed rating systems for specific building sectors and project scopes:

1. Core & Shell
2. New Construction
3. Schools
4. Neighborhood Development
5. Retail
6. Healthcare
7. Homes
8. Commercial Interiors

The latest evolution of LEED was in 2009.[12] In LEED 2009, the allocation of points between credits is based on the potential environmental impacts and human benefits of each credit with respect to a set of impact categories. The impacts are defined as the environmental or human effects of the design, construction, operation, and maintenance of the building, such as greenhouse gas, emissions, fossil fuel use, toxins, and carcinogens, are and water pollutants, and indoor environmental conditions (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009). The similarity between the EPA's definition and USGBC's definition is because LEED 2009 uses the EPA's environmental impact categories as the basis for weighting each credit. As of April 2013, there are 44,998 registered and certified buildings in the United States (U.S. Green Building Council). The LEED rating system removed ambiguity in the loosely interpreted concepts associated with sustainability and green building. LEED's newly articulated, cohesive rating system rapidly gained wide acceptance in both the private and public sectors and has

[12] LEED is planned to be updated again in 2012.

significantly impacted the construction industry in the most energy- and materials-intensive economy in the world (Kibert, 2008).

LEED can serve as a powerful a powerful tool for listing an array of project targets by utilizing the benchmarks and metrics it has established, through a consensus process, for measuring performance (Reed, 2009). LEED is subdivided into seven subcategories for which there are prerequisites, and credits representing possible points. As seen in Table 2.7, each category has its own allocated points that a project could obtain in order to achieve certification.

Table 2.7 LEED for New Construction Total Possible Points(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009)

LEED for New Construction	
Total Possible Points	110*
Sustainable Sites	26
Water Efficiency	10
Energy & Atmosphere	35
Materials & Resources	14
Indoor Environmental Quality	15
Innovation in Design	6
Regional Priority	4
*Certified 40+, Silver 50+, Gold 60+, Platinum 80+	

The total possible points are the maximum amount of points available per category. There is not a minimum amount of points per category, only overall among all categories, that a project needs to obtain certification. These points are based on the features specific to each category, which are discussed in depth below.

Sustainable site (SS) credits deal with issues *outside* of the building, including some of the building exterior, the land that is being developed, and the surrounding community (Haselbach, 2008). The sustainable sites category emphasizes on limiting the impact of buildings on local ecosystems by integrating the building location and sustainable features. In Table 2.8 below, all possible credits listed that may be obtained for certification (USGBC, 2009). All projects pursuing LEED certification *must* achieve all prerequisites, in all categories.

Table 2.8 Sustainable Sites Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 3)

Sustainable Sites		Possible Points 26
Prereq 1	Construction Activity Pollution Prevention	req
Credit 1	Site Selection	1
Credit 2	Development Density and Community Connectivity	5
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation - Public Transportation Access	6
Credit 4.2	Alternative Transportation - Bicycle Storage and Changing Rooms	1
Credit 4.3	Alternative Transportation - Low-Emitting / Fuel Efficient Vehicles	3
Credit 4.4	Alternative Transportation - Parking Capacity	2
Credit 5.1	Site Development - Protect or Restore Habitat	1
Credit 5.2	Site Development - Maximize Open Space	1
Credit 6.1	Stormwater Design - Quantity Control	1
Credit 6.2	Stormwater Design - Quality Control	1
Credit 7.1	Heat Island Effect - Non-roof	1
Credit 7.2	Heat Island Effect - Roof	1
Credit 8	Light Pollution Reduction	1

LEED 2009 summarizes the intent of sustainable site credits as follows (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009):

> Project teams undertaking building projects should be cognizant of the inherent impacts of development on the following:
>
> - Land consumption
> - Ecosystems
> - Natural resources
> - Energy use

Water efficiency (WE) credits deal with issues that reduce the use of potable water at the site and the discharge of wastewater from the site (Haselbach, 2008). The water efficiency prerequisites and credits address environmental concerns relating to building water used and disposal and promote 1) monitoring water consumption performance, 2) reducing indoor potable water consumption, 3) reducing water consumption to save energy and improve environmental well-being, and 4) practicing water-efficient landscaping (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009). Water efficiency credits are summarized in Table 2.9.

Table 2.9 Water Efficiency Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 163)

Water Efficiency		Possible Points 10
Prereq 1	Water Use Reduction - 20% Reduction	required
Credit 1	Water Efficient Landscaping	2 to 4
Credit 2	Innovative Wastewater Reduction	2
Credit 3	Water Use Reduction	2 to 4

Energy and Atmosphere (EA) credits deal with practices and policies that reduce the use of energy at the site, reduce the use of nonrenewable energy both at the site and at the energy source, and reduce the impact on the global climate, atmosphere, and environmental from both activities at the site and energy sources off-site (Haselbach, 2008). Energy and atmosphere credits are summarized below in Table 2.10 (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009).

Table 2.10 Energy and Atmosphere Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 215)

Energy and Atmosphere	Possible Points	35
Prereq 1	Fundamental Commissioning of Building Energy Systems	required
Prereq 2	Minimum Energy Performance	required
Prereq 3	Fundamental Refrigerant Management	required
Credit 1	Optimize Energy Performance	1 to 19
Credit 2	On-Site Renewable Energy	1 to 7
Credit 3	Enhanced Commissioning	2
Credit 4	Enhanced Refrigerant Management	2
Credit 5	Measurement and Verification	3
Credit 6	Green Power	2

Material and Resources (MR) credits deal with issues that reduce the use of new materials and resources, encourage the use of materials and resources that have a smaller impact on the environment, and promote the reuse or recycling of materials so that more virgin materials and resources are not used on LEED certified projects (Haselbach, 2008). Materials and resource credits are summarized below in Table 2.11 (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009).

Table 2.11 Materials and Resources Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 338)

Materials and Resources		Possible Points 14
Prereq 1	Storage and Collection of Recyclables	
Credit 1.1	Building Reuse - Maintain Existing Walls, Floors and Roof	1 to 3
Credit 1.2	Building Reuse - Maintain 50% of Interior non-Struct. Elements	1
Credit 2	Construction Waste Management	1 to 2
Credit 3	Materials Reuse	1 to 2
Credit 4	Recycled Content	1 to 2
Credit 5	Regional Materials	1 to 2
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1

Indoor Environmental Quality credits deal with materials and systems inside the building that affect the health and comfort of the occupants and construction workers (Haselback, 2008). Indoor Environmental Quality credits are summarized below in Table 2.12.

Table 2.12 Indoor Environmental Quality Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 405)

Indoor Environmental Quality		Possible Points 15
Prereq 1	Minimum Indoor Air Quality Performance	required
Prereq 2	Environmental Tobacco Smoke (ETS) Control	required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation	1
Credit 3.1	Construction IAQ Management Plan - Before Construction	1
Credit 3.2	Construction IAQ Management Plan - Before Occupancy	1
Credit 4.1	Low-Emitting Materials - Adhesives and Sealants	1
Credit 4.2	Low-Emitting Materials - Paints and Coatings	1
Credit 4.3	Low-Emitting Materials - Flooring Systems	1
Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Products	1
Credit 5	Indoor Chemical and Pollutant Source Control	1
Credit 6.1	Controllability of Systems - Lighting	1
Credit 6.2	Controllability of Systems - Thermal Comfort	1
Credit 7.1	Thermal Comfort - Design	1
Credit 7.2	Thermal Comfort - Verification	1
Credit 8.1	Daylight and Views - Daylight	1
Credit 8.2	Daylight and Views - Views	1

Innovation in Design (ID) credits deal with issues otherwise not included in the other categories, or which exceed to a specified degree some of the intents from the other credit categories (Haselbach, 2008). Credits can be achieved through any combination of the Innovation in Design and Exemplary Performance.[13] Innovation in Design credits are awarded when a project achieves significant, measureable environmental performance using a strategy not address in the LEED 2009 for New Construction and Major Renovations Rating System (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009). Credit 2, LEED Accredited

[13] Exemplary Performance points may be earned for achieving double the credit requirements and/or achieving the next incremental percentage threshold of an existing credit in LEED (USGBC, LEED 2009).

Professional, requires the project to have at least one principal project participant as a LEED Accredited Professional (AP) (USGBC, 2009).[14] Innovation in Design credits are summarized in Table 2.13.

Table 2.13 Innovation and Design Process Credits
(Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009, page 591)

Innovation and Design Process		Possible Points 6
Credit 1.1	Innovation in Design	1
Credit 1.2	Innovation in Design	1
Credit 1.3	Innovation in Design	1
Credit 1.4	Innovation in Design	1
Credit 1.5	Innovation in Design	1
Credit 2	LEED Accredited Professional	1

Regional priority (RP) credits, identified by USGBC regional councils and chapters, deal with issues of particular importance to specific areas (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009). Upon project registration, LEED-Online automatically determines a project's regional priority credits based on zip code. USGBC's intent with these credits is to provide an incentive for the achievement of credits that address geographically-specific environmental priorities (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009).

[14] The intent of this credit is to educate the project team members about green building design and construction, LEED requirements and application process early in the life of the project (USGBC, LEED 2009).

Registration for a LEED construction project with the USGBC is completed at the inception of a project to begin the certification process. The USGBC states that registration serves as a declaration of intent to certify a building under the LEED Green Building Rating Systems. Registration provides access to a variety of tools and resources necessary to apply for LEED certification (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009).

LEED Online is the primary resource for managing the LEED documentation process. LEED Online allows a project to manage project details, complete documentation requirements for LEED credits and prerequisites, upload supporting files, submit applications for review, receive reviewer feedback, and ultimately earn LEED certification. It also provides a common space where members of a project team can work together to document compliance with the rating system. All projects must be certified using LEED Online (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction, 2009).[15]

2.5.1. Risks Associated with LEED: Limitations of LEED. As stated above, LEED is a tool. Using LEED well as a tool means pursuing performance targets based on the *intent* of each credit and understanding that each of the “credits” represents one or more environmental issues that are deeply interrelated. Using LEED *poorly* means going through the credit checklist and picking individual points to pursue as though you could pick and choose the cheapest items from a menu, often referred to as “point shopping” (Reed, 2009)

---

[15] LEED for Homes is the exception to this requirement.

Many projects mistakenly assume that the only real question is whether to seek LEED certification from the USGBC. However, the decision to seek LEED certification, unsupported by a commitment to integrated design is likely to be a recipe for frustration and ultimate futility. Many projects registered under the LEED system have failed to finish the process because sustainable design involves a far boarded set of considerations, than just LEED alone (Yudelson, 2009).

One way to verify if a building has not only achieved certification, but is actually meeting the intent of the credit (specifically Energy and Atmosphere credits), is through continued measurement of energy usage. The LEED program awards energy performance points on the basis of predicting energy cost saving compared to a modeled code baseline building. The baseline is generated using the energy cost budget (ECB) approach and performance requirements in the ASHRAE 90.1[16] standard (Turner, 2008). In 2008, the New Building Institute conducted a study to analyze energy performance for 121 LEED New Construction buildings. The study was commissioned by USGBC with the purpose to provide a critical information link between intention and outcome for LEED projects. The requirement for inclusion in the study was the ability to provide at least one full year of measured post-occupancy energy usage date for the entire LEED project (Turner, 2008). Although 552 buildings were certified through 2006, only 121 buildings were able to provide the requested information and were included in the results. On average, measured performance results show that LEED buildings are energy saving (Turner, 2008). LEED buildings on average, use 25-30% less energy than the national average, a level similar to that anticipated by LEED modeling; however, some buildings

[16] American Society of Heating, Refrigeration and Air-Conditioning Engineers

are doing *worse* than the baseline performance requirements as established by ASHRAE 90.1 (Turner, 2008).

While most of the projects measure energy savings, measuring from 0% up to nearly 90%, it is startling that there are projects that measured losses in energy. Even more startling is that six gold or platinum buildings were among the projects with energy losses. As previously discussed in Section 2.3.4 Risks Related to Sustainable Construction, added cost can be a perceived risk in sustainable construction. Ideally, the additional costs are recouped during the life of the building because of lower energy costs. Variation in results is likely to come from a number of sources, including differences in operational practices and schedules, equipment, construction changes and other issues not anticipated in the energy modeling process. Follow-up investigation into reasons for measured-to-design deviations, and for the wide variations in modeled baseline performance, could improve future modeling and benchmarking (Turner, 2008). The New Buildings Institute Study concluded that related LEED credits such as Advanced Commissioning (EA Credit 3) and Measurement and Verification (EA Credit 5) could be reworked to more directly contribute to better energy performance and provide more directly useful information to owners and operators (Turner, 2008).

As previously discussed, many facets of sustainable construction are intertwined and interrelated. LEED APs can use this synergy of sustainable construction to their advantage when planning which credits to pursue on a project. Early in the LEED adoption process, practitioners found that could be credits could be linked, and allow for achieving points for under two different criteria. For example, Sustainable Sites credit 7.2, regarding heat island effect in roofs, aids in stormwater runoff control in Sustainable

Sites credits 6.1 and 6.2 (stormwater design), and aids in energy conservation and thermal control in Energy and Atmosphere credit 1 (optimize energy performance) (Lavy, 2009). On the other hand, certain credits preclude the possibility of gaining points in other credits; for example, Material and Resource credits 5 and 6 regarding regional materials and rapidly renewable materials may conflict and a project could only pursue one of the two credits; for example, most bamboo flooring (rapidly renewable) is from China, and most linoleum (rapidly renewable) is from Europe, which would not make those materials compliant with a regional criteria of being within 500 miles of the project (Yudelson, 2007).

The two other major factors affecting point selection are cost (real or perceived) and the level of complexity (of the point under selection). The level of complexity of a particular LEED point can be established as a measurement that depends on factors such as design team expertise, competency, and team integration (Lavy, 2009).

LEED awards points for five major influences of construction on environmental quality. The five major areas include (Yudelson, 2007).

- Reduction of site impacts from construction staging by keeping all equipment and soil disturbance within specified limits to avoid soil compaction.
- Construction waste recycling of at least 50% of materials, with extra points awarded for 75% and 95% waste diversion. This not only keeps materials out of landfills but recovers valuable products for recycling. In most urban areas, contractors are discovering they can recycle or recover more than 90% of construction waste and that is economically beneficial for them, given the high cost of landfilling. Recycling such items as cardboard, metal, brick, acoustic ceiling tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet, and insulation is surprisingly simple. In some cities, wastes can be co-mingled.
- Indoor air-quality assurance before occupancy by conducting a two-week building flush-out with 100% outside air and changing all filters before occupancy, or by conducting a test of key indoor air-quality contaminants to make sure they are below threshold levels for health effects.

- Monitoring the activities of subcontractors to make sure that specified low-VOC paints and coatings, adhesives and sealants are actually used on the project without substitution.

General contractors must maintain documentation to demonstrate that the project is in compliance with the LEED credits.   In addition to the five major construction influences, there are two areas where construction influence is integrated with design, but the contractor becomes responsible for ensuring compliance with the credits and for maintaining the necessary documentation. These two facets of LEED are Materials & Resources and Energy & Atmosphere credits. Materials & Resources credits for building reuse, materials reuse, recycled content, regional materials, rapidly renewable resources, and certified wood are primarily construction submittals (as opposed to design submittals) (Haselbach, 2008). Energy & Atmosphere credits for fundamental commissioning (prerequisite), enhanced commissioning, measurement and verification, and green power are also construction submittals (Haselbach, 2008).

2.6. SUSTAINABILITY IN HIGHER EDUCATION CONSTRUCTION

Colleges and universities are national leaders in sustainability, especially when it comes to green building standards and policies. The motivation for sustainability on college and university campuses resonates from a mission that encompasses a moral responsibility to institute sustainable practices and to address global climate change. Likewise, their mission to educate tomorrow's leaders enables them to have a significant, positive impact on efforts to reduce humanity's climate footprint (Button, 2009). Sustainable construction planning and development offers an opportunity to leverage talents of professors and experts across disciplines, and to think strategically and long-term about the campus and it's systems as a whole (Ried, 2008).

A college or university may be the largest employer in a town or city; it can have a huge impact on energy use, carbon footprint, water use and other municipal services (Yudelson, 2007). Many of the larger universities produce greenhouse gas emissions equivalent to small cities (Button, 2009). Sustainability planning within an institution can positively impact the local community and foster positive relationships between university and city. Universities and colleges have tremendous economic and fiscal impact as well as physical impact on local infrastructure and resources. Demonstrating a commitment to reducing negative environmental impacts while stimulating the local economy through local purchasing programs through sustainable planning and development provides an opportunity for a university to serve as a responsible developer and for new avenues for coordination between universities, the surrounding community, and the city as a whole (Ried, 2008).

On average, between 2002 and 2009, buildings on college and university campuses accounted for 15% of all LEED project registration (Galayada, 2010). Table 2.14 below illustrates the top ten universities across the country in terms of LEED projects (Galayada, 2010).

Table 2.14 Top Ten Universities in Terms of LEED Projects
(Galayda, 2010, Page 4)

Top Ten Universities in Terms of LEED Projects	
University	**Total LEED Projects**
Cornell University	17
Duke University	24
Emory University	16
Harvard University	39
University of Colorado-Boulder	18
University of Florida	60
UC-Santa Barbara	33
University of Virginia	20
University of Washington	26

While leadership structure varies between the schools identified above, all schools stressed the importance of commitment to green design and sustainability at the top and middle levels of leadership (Ried, 2008). The universities also participate in organizations that promote sustainable efforts, including the Association for the Advancement of Sustainability in Higher Education (AASHE)[17] and the Association of University Leaders for a Sustainable Future (ULSF)[18] (Ried, 2008).

[17] The mission of AASHE is to empower higher education to lead the sustainability transformation by providing resources, processional development, and a network of support to enable institutions of higher education to model and advance sustainability in everything they do, from governance and operations to education and research.
[18] The mission of ULSF is to support sustainability as a critical focus of teaching, research, operations and outreach at colleges and universities worldwide through publications, research, and assessment.

2.7. CONTRACT DELIVERY METHODS

A design-bid-build contract is commonly used for projects that have no unusual features and a well-defined scope.[19] It is a three-party arrangement involving the owner, design (or architect), and a general contractor. Design-bid-build is often considered the traditional project delivery method. This method involves three steps (Oberlender, 2000):

1. A complete design is prepared
2. Solicitation of competitive bids from contractors
3. Award of a contract to a construction contractor to build the project

Two separate contracts are awarded from the owner; one to the designer and one to the general contractor. Since a complete design is prepared before construction, the owner knows the project's configuration and approximate cost before commencing construction. Considerable time can be required because each step much be completed before starting the next step. All design work is completed before starting the bid and construction process. This delivery method is usually selected for projects when cost is primary, schedule is secondary, and the scope is well defined. Also changes during construction can be expensive because the award of the construction contract is usually based upon a lump-sum, fixed price bid before construction, rather than during construction (Oberlender, 2000). Figure 2.1 below illustrates the fundamental arrangement for handling a design-bid-build project, in its simplest form:

---

[19] Unusual features and well defined scope

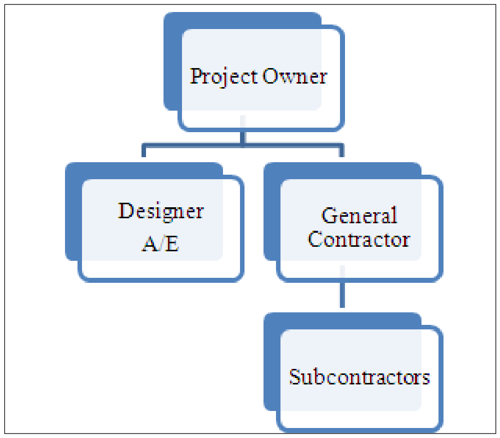


Figure 2.1 Design Bid Build Contract Arrangement
(Oberlender, 2000, page 34)

The design phase of the type of construction delivery method could take anywhere from a year to two years. After the design is complete, it is given to the construction professionals for bid. These contractors, who are not typically involved in the design process, have up to four weeks to bid on the documents (Reed, 2009). Not only are the contractors given only up to four weeks to understand hundreds of hours worth of information, but they are also asked to put a price on that understanding and further, to commit contractually to meeting that price (Reed, 2009).

For the past half-century, the dominant design and construction process for buildings has been understood as a three-step process: architects and engineers (A/E) design the entire buildings, bids are solicited from contractors, and contractors construct the buildings (Hallowell, 2009). Current design-bid-build models assume that engineering and design are only performed by A/Es, and their specialty engineering and design consultants. Conversely, general contractors and subcontractors only provide construction services, and material vendors only manufacture and deliver (Hallowell, 2009).

Hallowell and Toole hypothesized that on design-bid-build projects, a substantial number of build performance engineering tasks are typically provided by entities associated with the construction phase, not with the A/E of record. Their hypothesis continued that there has been a gradual, but significant, shift in the engineering of a building from recognized design professionals to entities associated with construction of designs, namely, constructors and material component manufacturers. Hallowell and Toole took the linear model in Figure 2.9 Design Bid Build Contract Arrangement, and evolved it to a more contemporary model between the project participants with much more of an interactive relationship between the A/E and the construction phase project participants. While the interaction between the A/E and the construction phase project participants is not formally contractual, it does occur earlier and more often than the traditional design-bid-build model. The research conducted by Hallowell and Toole is broad, but important enough to warrant a substantial number of confirmatory investigations (Hallowell, 2009).

A design-build contract is a two-party arrangement between the owner and the design/build firm. Design-build is defined as an alternative project delivery method that encompasses both project design and construction under one contract (Lam, 2008). A design-build contract is often used to shorten the time required to complete a project or to provide flexibility for the owner to make changes in the project during construction. This method requires extensive involvement of the owner for decisions that are made during the selection of design alternatives and the monitoring of costs and schedules during construction (Oberlender, 2000). The design-build project delivery method is usually selected for projects when the schedule is primary, the cost sis secondary, and the scope is not well defined. Figure 2.2 illustrates the fundamental arrangement for handling a design-build project:

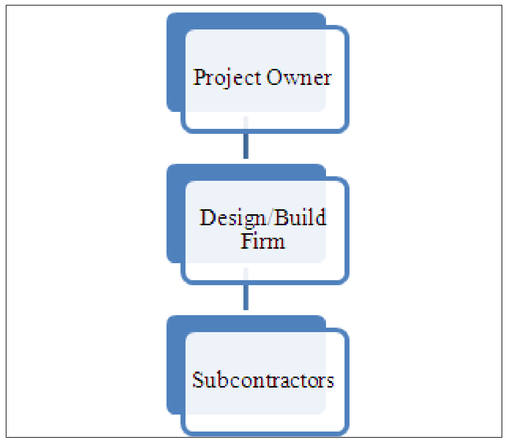


Figure 2.2 Design Build Contract Arrangement
(Oberlender, 2000, page 34)

The design-build project delivery system became more widely used over the last 30 years (Lam, 2008). Less than 20 years ago, this concept was still the subject of intense scrutiny by public agencies and intense research by the academia (Minchin, 2010). Success criteria for design-build projects are on budget, on schedule, and conform to user's expectations, which are all consistent with the success criteria of a construction project in general (Lam, 2008). In order to achieve success, a design-build contract relies on the following factors (Lam, 2008):

1. Clearly defined scope

2. Cohesive relationship among project participants
3. Experienced and confident general contractor
4. Ability to maintain proper documentation
5. End user's input

A study was conducted to compare design-bid-build with design-build projects with a goal of determining which project delivery method was superior in regards to time and cost (Hale, 2009). The study examined 77 projects managed by the Naval Facilities Engineering Command (NAVFAC). Of the 77 projects, 39 were design-bid-build and 38 were design-build; all projects were similar in scope. The results pointed out that design-build projects were a superior project delivery method; design-build projects took less time to complete and had less time and cost growth (Hale, 2009). The authors of the study noted that care should be taken when extending the results because of the homogeneous nature of the study. The study did not address the issues of sustainable construction, nor did it address the owner's decision-making process when determining the delivery method of the project.

Research was conducted by Iowa State University to present the advantages and disadvantages of utilizing design-build (as opposed to design-bid-build) on military construction projects (Ahn, 2011). The research consisted of analyzing 75 design-build projects and 44 design-bid-build projects for characteristics including duration change, schedule growth, project cost growth, and project placement per day. The study found that design-build projects did experience a lower cost of changes orders. There was no significant difference in project performance or in schedule performance (Ahn, 2011). The study attributed the lack of increased schedule performance on the nature of military construction. While the purpose of the study was valuable to the study of construction management and project delivery methods, the study was too broad to draw any substantial conclusions.

Integrated building design is the high level of collaboration and teamwork that help differentiate a sustainable building design from the design process of a conventional project. According to the U.S. Department of Energy, integrated design is (Kibert, 2008):

> *A process in which multiple disciplines and seemingly unrelated aspects of design are integrated in a manner that permits synergistic benefits to be realized. The goal is to achieve high performance and multiple benefits at a lower cost than the total for all the components combined. This process often includes integrating green design strategies into conventional design criteria for building form, function, performance, and cost. A key to successful integrated building design is the participation of people from different specialties of design: general architecture, HVAC, lighting and electrical, interior design, and landscape design.*

The integrative design team consists of many people working to grow an understanding of the many subsystems within the whole system to create a collaborative intelligence (Reed, 2009, Blacud, 2009). The core of the team consists of a dynamic relationship of the design team, client, and builder. Surrounding the core team are many stakeholders including (Reed, 2009):

- Owner
- Community members
- Facilities manager
- Planning staff
- O&M staff
- Cost estimator
- MEP contractor
- General contractor
- Construction manager
- Product manufacturers
- Daylighting/energy analyst
- Commissioning agent
- Landscape architect
- Civil engineer

- Planner
- Architect
- Structural engineer
- MEP engineer
- Building users

As the construction industry strives for closer integration of the participants, more responsibility for the management of the detailed design process is being directed to main contractors and combined with their existing duties of managing the construction and pre-construction processes (Mitchell, 2011). The design process is one of refining solutions to a set of problems and reducing uncertainties, while construction is the creation of a product and must therefore close out all uncertainties, included those that devolved to it from the design process (Mitchell, 2011).

2.8. SUMMARY

Suggested future research interests are many. First, while there are many existing case studies about the performance and cost of sustainable projects, there are few case studies about the project management processes and integrated team approaches applies on such projects (Robichaud, 2011). Review of the literature in Section 2 highlighted the importance of studying a sustainable construction project in order to identify means and methods useful to future projects. Section 2 also introduced the risks related to sustainable construction; however the research did not find evidence as to why these barriers are still in existence and how they can be overcome.

3. METHODOLOGY

3.1. RESEARCH OBJECTIVE

The research goal of this dissertation is to determine if detailed construction management processes, including waste management, material procurement, indoor air quality, and commissioning can be applied to the bid and build phases of a sustainable construction, design-bid-build procurement project to obtain LEED certification to overcome the existing barriers to sustainable construction. The design phase is not considered in this research because it is beyond the scope of a construction manager's responsibilities on a design-bid-build contract. The design lies with the architect or engineer of record. There are currently processes that are used on design-bid-build projects; however, they are ill-defined in the actual implementation for in-field construction projects. Current research details the *what* to do, but not the *how* to do it. For example, research from Section 2 discusses that subcontractors should be involved in the waste collection and disposal, but no method for subcontractor involvement is detailed. The goal of this research is to provide answers to how to implement successful process on a sustainable construction project and achieve LEED certification, while overcoming the existing barriers to sustainable construction.

The purpose of this section is to detail how this research will test the objective outlined in the paragraph above. Three means were utilized in this research to identify 1) the existing barriers to sustainable construction, 2) the need for construction management practices to alleviate these barriers, and 3) a validation of the construction management practices. These three means are focus group, survey, industrial application.

This section will expound upon the purpose of these three validation methods, specifically how and why each was utilized.

3.2. FOCUS GROUP DEVELOPMENT AND EXECUTION

The purpose of this focus group utilized in this research was to analyze how construction industry professionals, with LEED and sustainable construction experience, think barriers to sustainable construction have not been overcome. A secondary purpose of the focus group was to determine if the construction industry professionals have experience or ideas concerning construction management methods that make a project more efficient and lead to successful LEED certification This is a less rigid and structured approach because the participants will be encouraged to discuss the issues, as opposed to only provide a direct answer; the aim of this focus group is to understand the participants' meanings and interpretations (Liamputtong, 2011).

This focus group consisted of four professionals who currently work in the construction industry, which was within the target number (between four to ten). If there were more than 10, the discussion would be too diluted or cumbersome to obtain quality responses to the questions. If there were less than four, the conversation may be limited and/or there may not be a proper representation of experience and ideas. The focus group participants had experience with sustainable construction management practices that have been successful and have led to LEED certification. They were also employed at and/or have previous employment at a construction management firm that specializes in sustainable construction. This type of company typically utilizes the latest techniques and has a robust training plan to ensure that the employees are knowledgeable and well trained. For this particular focus group, participants from DPR Construction were ideal. DPR Construction states the following, related to its purpose:

> *DPR Construction they exist to build great things. They are a company of builders building great projects, great teams, great relationships, and great value. Great value in today's world means leaning forward to own the technicalities of what sustainable construction is all about. In a relatively new way of construction, building sustainable projects is a very unique process that is never the same. However, having the fundamental knowledge of the sustainable basics outlined by the USGBC along with the experience DPR Construction has proven in sustainable construction projects in the past along with the way they are re-defining sustainable construction, makes them an easy choice for this focus group.DPR understand that building sustainable projects routinely produce greater employee productivity, improved operating and maintenance costs and also greater marketability for customers. Thus, DPR has shown through experience that it has the knowledge available in house to fit customer's needs from a design perspectives, train sub-contractors and other builders executing the work, and the leaders to turn customer's concept into efficient constructible reality. DPRs sustainable construction resume includes the UCSF medical center at Mission Bay, the Palomar Medical Center, the JW Marriott Austin, the VMWare Corporate Campus, the Facebook Prineville Data Center, the Facebook Sweden Data Center, the Biodesign Inst at ASU Buildings A and B, the University of California San Francisco Regeneration Medicine Bldg, to name a small percentage of the DPR sustainable project portfolio. These projects represent LEED certified projects from the certified to the platinum level.*

The participants of this focus group were experienced and successful and have seen barriers to sustainable construction, while overcoming them and completing a project. It would have been detrimental to this focus group if it was full of people that still held onto the preconceived ideas about sustainable construction. The participants were invested in the success of construction management practices on sustainable projects because they had financial and professional investment in such management. These participants have dedicated significant time and effort to implement such management methods.

This research also utilized a survey to target a broad range of industry professions with varying levels of experience with sustainable construction; in contrast, this focus group targeted a smaller, more experienced and educated group. The participants were homogeneous in that they all worked in construction management and they had education and/or training in sustainable/LEED construction. They were heterogeneous in their age and range of experience (i.e., number of projects and level of LEED certification, and past experience).

The focus group was recorded. The following questions were asked during the focus group:

1. What is your experience in the construction industry and specifically, with sustainable construction?
2. Do barriers to sustainable construction still exist? What are they? Why have they not been overcome?
3. What are some ways that you communicate the sustainable contract requirements with your subcontractors? On a scale of 1-5, how successful have they been?
4. What are some tracking techniques that you use to ensure that you comply with LEED credits through the construction of the project? On a scale of 1-5, how successful have they been? Scale:
    1- Not successful
    2- Limited success
    3-Neutral
    4-Successful
    5-Very successful
    6-Not applicable

The answers to the questions, and the discussion that the questions prompted, were analyzed like a conversation (as opposed to an interview) with attention to the context and sensitivity to what was said earlier in the conversation (Krueger, 2006). The analysis was verified through inter-rater reliability, and will be discussed in the appropriate sections throughout the rest of this section.

3.3. SURVEY DEVELOPMENT AND EXECUTION

In addition to the broad literature review that was performed concerning the sustainable construction factors; a survey was conducted to determine which construction management methods were both needed and useful. The survey was developed using a goal question metric approach (Basili, 1994), as illustrated in Table 3.1.

Table 3.1 Goal Question Metric Development

Goal	Purpose Issue Viewpoint	Evaluate the experience construction industry professionals
Questions		What is your area of expertise? How many years experience do you have in the construction industry? Are you a LEED GA or LEED AP? Have you worked on a project(s) that earned LEED certification? What was the type of project? What was the value of the project(s)? What was your role? Have you worked on a sustainable project which did not pursue LEED certification (Where sustainable is defined as reduced negative environmental impacts through high-performance construction and operations practices?
Metrics		Multiple choice list Yes/No
Goal	Purpose Issue Viewpoint	Compare responses from LEED projects to non-LEED projects
Questions		Are you a LEED GA or LEED AP? Have you worked on a project(s) that earned LEED certification? What was the type of project? What was your role? How often does the project management conduct site visits?
Metrics		Multiple choice list Yes/no
Goal	Purpose Issue Process	Evaluate construction management process construction waste management

Viewpoint	from the project manager’s viewpoint
Questions	Do you have a standardized process for waste collection? An example would be a written, transferable process within your organization. Do your subcontractors break out a line item for the cost of construction waste management in its bid? If not, would it be helpful? Does your contract with the owner typically have a clause for waste management that identifies the requirement for recycling construction debris? If not, would it be helpful? Do you have a contract clause with your subcontractors for recycling of construction debris? If not, would it be helpful? Would a standardized process for waste collection be helpful?
Metrics	Yes/no Descriptive narrative from construction manager experience Likert scale
Goal Purpose Issue Process Viewpoint	Evaluate construction management process materials resource management from the project manager’s viewpoint
Questions	Do you require subcontractors to itemize their materials with regards to LEED criteria in their bid? Do you track material quantities incrementally throughout the project? If yes, do you require the subcontractors to be responsible for tracking? If yes, who is responsible for compiling all input from the subcontractors?
Metrics	Yes/no Descriptive narrative from construction manager experience Likert scale
Goal Purpose Issue Process Viewpoint	Evaluate construction management process indoor air quality from the project manager’s viewpoint
Goal Purpose Issue Process Viewpoint	Evaluate construction management process commissioning from the project manager’s viewpoint
Questions	How do you disseminate the commissioning plan to all applicable subcontractors?
Metrics	Descriptive narrative from construction manager experience

A 23 question questionnaire was created for the purpose of this research. Survey respondents evaluated the sustainable construction factors presented in each question. Their evaluations were established based on their experience within the construction industry (project management, architecture, and/or construction management). Zoomerang Online Surveys was utilized to execute the survey in September 11, 2012. Approximately 950 industry professionals within the field of construction were invited to participate in the survey. See Table 3.1 for a list of the questions and the goal-question-metric mapping that was formulated to produce the survey. The on-line survey was closed two weeks later on September 25, 2012, with 81 responses, reflecting an 8.5% response rate. The demographics of the respondents included 40.7% LEED Accredited Professionals, 70% have worked on a LEED certified project, and 18% have earned platinum level certification.

3.4. INDUSTRIAL APPLICATION DEVELOPMENT AND EXECUTION

An industrial application was used to validate the proposed construction management methods to be utilized on a sustainable project to overcome the existing barriers to sustainable construction. An industrial application as a means of validating the management practices allowed for a detailed and in-depth look at how these management practices are implemented on a day-to-day basis. This is particularly important because the day-to-day rhythm of a project can swing from either monotonous to highly dynamic, but ultimately decisions are made because of the way systems and/or processes are established on a project. The conclusions drawn from an industrial application can be applied to other projects even though each project is unique. This is because although each project produces unique issues that require decisions, the processes in place establish the conditions for drawing the necessary conclusions to address the issues.

In order to collect the details and information necessary to complete a thorough analysis of the industrial application project, interviews were conducted on a regular basis from July 2011 through April 2012 with the project field engineer. A series of 14 interviews was conducted over the 10 month period at the project site. Interviews were conducted during construction and after completion of the project. These interviews focused on questions developed to determine the effect of LEED certification of the project, as well as the methods used to successfully pursue LEED certification as the silver level, specific to credits obtained by the construction manager. The project end used was also interviewed to determine the success of the project in meeting the needs of the owner as well as the evolution of the LEED requirements, from design and pre-construction, through project completion.

Documentation was collected in order to obtain a full picture of the events of the project. The project documentation is vital to understanding the nuances of the project because it is the official record of the project. It contains the official requirements of the project, through the plans and specifications. It also creates a clear depiction of the events of the project through multiple points of view by tracking the course of the project through meeting minutes. In conjunction with the interviews that were conducted with key project personnel, the project documentation was used to analyze how the project was executed and how LEED credits were obtained. Below is a list of the different forms of project documentation that were reviewed in the analysis of this industrial application:

- Meeting Minutes – Owner, Architect, Contractor (OAC) meetings
- Plans & Specifications – conformed documents created by the project architect to meet the needs of the owner and used by the construction manger to execute construction of the project.
- Submittals – all submittals related to LEED requirements, as well as all submittals from the subcontractors to the prime contractor, and the submittal register used to track submissions.
- Photos – photos taken by the construction manager need to document compliance with LEED requirement and earn the LEED credits.
- LEED Documentation – all documentation required to illustrate compliance with LEED requirements and earn the LEED credits.

4. FINDINGS

4.1. FINDINGS OBJECTIVES

The objective of this section is to present the findings of the focus group and case study. There are two categories to this research; 1) more insight on the problems inherent to sustainable construction through testing and analysis of the existing barriers to sustainable construction, and 2) the construction management methods to overcome the existing barriers. Analysis of the focus group introduced in Section 3 will provide the insight on the existing problems inherent to sustainable construction. Analysis of the survey introduced in Section 3 will provide insight on the need for construction management process on sustainable projects.

Table 4.1 lists the existing barriers to sustainable construction and the corresponding reasons why they still remain. These barriers were first identified in the Section 2 Background section entitled "Risks Related to Sustainable Construction" (Kibert, 2008, Robichaud, 2011, Matthiessen, 2007). The reason that the barriers have not been overcome is the topic of this section as listed in Table 4.1 below:

Table 4.1 Existing Barriers to Sustainable Construction

Barrier	Reason that the barrier has not been overcome
Perception	Lack of awareness and bad experience – bad experience gives industry professionals a poor perception of constructing a sustainable project.
Lack of experience	Many mid- to small size general contractors have limited experience with sustainable construction, or the experience they do have left a bad impression – professionals with limited experience concerning sustainable construction are not likely to construct a sustainable project.
Current construction culture	Prevalence of conventional thinking – conventional thinking discourages contractors from constructing a sustainable project.

In addition to the existing barriers, this industrial application and focus group will also prove through testing the hypotheses classified under Methods to Overcome Existing Barriers to Sustainable Construction in Table 4.1, that the proposed methods for sustainable construction management will overcome these barriers. Evidence will be presented in this section that the existing barriers can be overcome by the following methods, listed in Table 4.2.

Table 4.2 Methods to Overcome Existing Barriers to Sustainable Construction

Barrier	Method to overcome barrier[20]
Perception	1) Hold meetings that communicate expectations and progress to identify if expectations are met; 2) project inspections – provide education in conjunction with experience and open communication in order to facilitate understanding of the project's sustainable requirements.
Lack of experience	Hold meetings that communicate expectations and progress to identify if expectations are met – provide education in conjunction with experience and open communication in order to facilitate understanding of the project's sustainable requirements.
Current construction culture	Checklists, inspections, coordination – bridge the gap between new ideas and old ideas by translating new criteria into conventional methods of operating.

4.1.1. Section Organization. This section will be organized based on the scientific methods used to prove the findings of this research. First, the focus group will be presented to include its development, execution, analysis, and findings. The analysis and findings will be separated by existing barriers to sustainable construction and then the construction management methods to overcome the barriers. Following the focus group, the industrial application will be presented in a similar organization as the focus group. This will include its development and execution, followed by background information on the project used as the industrial application prior to the analysis and findings. Finally, the summary of this section will encapsulate how the construction management methods identified in this research overcome the existing barriers on sustainable construction projects and how they lead to successful achievement of LEED certification. Once the existing barriers to sustainable construction are identified, the

[20] These methods were first proposed in the Section 3 Sustainable Construction Management Practices sections 'Construction Waste Management Process', 'Materials and Resources', 'Indoor Air Quality Process', and 'Commissioning.' The processes were summarized in the section titled 'Summary.'

methods to overcome the barriers will be summarized in order of construction waste management, materials and resources, indoor air quality, and commissioning. The purpose of this organization is to correlate the identified methods to the LEED credits that construction managers are responsible for on the project.

4.2. FOCUS GROUP

A total of 28 questions were asked and two raters independently assigned a numeric value to each question, on a scale from 1 to 5. The two raters independently assigned the same value 24 out of the 28 questions, for an 85.7% match rate. The first rater was the author of this research. The second rater was an industry professional with over eight years of experience in construction management and a LEED Accredited Professional. The second rater did not attend the focus group, but was given a transcript of the key statements. The rubric and rating criteria, along with the corresponding statement that was rated is as follows in Table 4.3.

Table 4.3 Focus Group Evaluation

Statement from Focus Group	**Evaluation Question**	**Rubric**	**Evaluation Question**	**Rubric**
1."Still a huge amount of resistance… Green doesn't pay, green is too expensive. Still a lot of misconceptions." 2. "A lot of owners still think it is a costly endeavor, not necessary." 3. "There is an onerous perception that the money they are paying, there is no real value to that" (certification). 4. "Most of the time it comes down to dollars. There is a certification process with a fee associated. People think, 'Why should we pay for that if we don't have to?' There is a huge organization that has been built over the last 20 years, that provides guidance that essentially you don't want to pay for it." 5. "Subcontractors are still resistant to implementing the LEED guidance." 6. "They hear stories from people throughout the industry. You submit all your points to USGBC. And they come back with petty little things to dispute it and there is a cost and it puts a bad taste in folks mouth because it is obvious that the effort is there but there is this entity that says, if you want to argue with me its $500. So you are weighing this scorecard...should I do this or that?" 7. "USGBC is questioning	Does this statement indicate that the industry professional has had a negative experience with sustainable construction?	1-Very negative 2- Slightly negative 3-Neutral 4- Positive 5- Very positive	Does this statement indicate that there is a poor perception of sustainable construction?	1- Very poor 2- Slightly poor 3- Neutral 4- Positive 5- Very positive

things that work in the field… lots of negative questions about what is LEED, USGBC?"				
5. "Subcontractors are still resistant to implementing the LEED guidance." 6. "There are still folks that do not have the resources, do not understand what you are asking." 7. "They are very inexperienced with what the requirements are. We have enough problems just trying to get a normal submittal. It seems to be getting worse. Part of it is a lack of education and training. Another problem is they don't have the manpower due to cost costing."	Does this statement indicate that the industry professional has experience with LEED construction?	1- No experience 2- Some experience 3- Neutral 4- moderate experience 5- High level of experience	Is this individual likely to construct a LEED project?	1- Highly unlikely 2- Somewhat unlikely 3- Neutral 4- Likely 5- Very likely
1. "Still a huge amount of resistance… Green doesn't pay, Green is too expensive. Still a lot of misconceptions." 2. "Subcontractors are still resistant to implementing the LEED guidance." 3. "You still have to wrangle them (subcontractors). VOCs, recycled content… it is another layer of paperwork. Some are proactive, some of them are not. You have to chase them." 4. "There are still folks that do not have the resources, do not understand what you are asking."	Does this statement indicate a prevalence of conventional thinking in construction?	1- Strong level of conventional thinking 2- Moderate level of conventional thinking 3- neutral 4- Low level of conventional thinking 5- Unconventional thinking	Is this individual likely to construct a LEED project?	1- Highly unlikely 2- Somewhat unlikely 3- Neutral 4- Likely 5- Very likely

The results from the inter rater reliability are summarized in the Table 4.4 below and will be addressed in more detail in this section.

Table 4.4 Inter-rater Reliability Results

Perception							
	Does this statement indicate that the industry professional has had a negative experience with sustainable construction?	Rater 1	Rater 2		Does this statement indicate that there is a poor perception of sustainable construction?	Rater 1	Rater 2
Statement and/or event	Rubric				Rubric		
"Still a huge amount of resistance… Green doesn't pay, Green is too expensive. Still a lot of misconceptions."	Very negative -1	1	1		Very poor - 1	1	1
"A lot of owners still think it is a costly endeavor, not necessary."	Slightly negative - 2	2	2		Slightly poor - 2	1	1
"There is an onerous perception that the money they are paying, there is no real value to that" (certification).	Neutral - 3	1	1		Neutral - 3	1	1
"Most of the time it comes down to dollars. There is a certification process with a fee associated. People think, 'Why should we pay for that if we don't have to?' There is a huge organization that has been built over the last 20 years, that provides guidance, that essentially you don't want to pay for it."	Positive - 4	2	2		Positive - 4	2	1
"Subcontractors are still resistant to implementing the LEED guidance."	Very positive - 5	2	2		Very positive - 5	2	2
"They hear stories from people throughout the industry. You submit all your points to USGBC. And they come back with petty little things to dispute it and there is a cost and it puts a bad taste in folks mouth because it is obvious that the effort is there but there is this entity that says, if you want to argue with me its $500. So you are weighing this scorecard...should I do this or that?"		1	1			1	1
"USGBC is questioning things that work in the field… lots of negative questions about what is LEED, USGBC?"		2	2			2	2
Lack of Experience							
	Does this statement indicate that the industry professional has experience with LEED construction?				Is this individual more likely to construct a LEED project?		
"Subcontractors are still resistant to implementing the LEED guidance."	No experience - 1	1	2		Highly unlikely - 1	2	2
"There are still folks that do not have the resources, do not understand what you are asking."	Some experience - 2	1	1		Somewhat unlikely - 2	1	1
"They are very inexperienced with what the requirements are. We have enough problems just trying to get a normal submittal. It seems to be getting worse. Part of it is a lack of education and training. Another problem is they don't have the manpower due to cost costing."	Neutral - 3	1	1		Neutral - 3	2	1
	Moderate experience - 4				Likely - 4		
	High level of experience - 5				Very likely - 5		
Current Construction Culture							
	Does this statement indicate a prevalence of conventional thinking in construction?				Is this individual likely to construct a sustainable project?		
"Still a huge amount of resistance… Green doesn't pay, Green is too expensive. Still a lot of misconceptions."	A strong level of conventional thinking - 1	1	1		Highly unlikely - 1	1	1
"Subcontractors are still resistant to implementing the LEED guidance."	A moderate level of conventional thinking - 2	2	2		Somewhat unlikely - 2	2	2
"You still have to wrangle them (subcontractors). VOCs, recycled content… it is another layer of paperwork. Some are proactive, some of them are not. You have to chase them."	Neutral - 3	2	2		Neutral - 3	2	1
"There are still folks that do not have the resources, do not understand what you are asking."	A low level of conventional thinking - 4	1	1		Likely - 4	1	1
	Unconventional thinking - 5				Very likely - 5		
28	Total						
24	Matches						
4	Misses						
86%	%						

4.2.1. Existing Barriers to Sustainable Construction. *Perception* as a barrier to sustainable construction was first discussed in Section 2, section "Risks Related to

Sustainable Construction” (Kibert, 2008, Robichaud, 2011, Matthiessen, 2007). Sustainable construction continues to have a poor perception among industry professionals. The poor perception stems from a high level of perceived risk, prior bad experience, and the misconception that sustainable construction includes significant additional costs (Morris, 2007).

A focus group was conducted with industry professions and an industrial application was conducted on the UVU New Science Building project. These two methods were used in conjunction, thus providing an examination from the prospective of experienced and successful industry professionals, as well as a close examination of a current construction project. This section will focus on the focus group findings and the industrial application will be analyzed later in the section.

Several statements were gathered from the focus group that related to the issue of bad experience leading to poor perception of constructing a sustainable project. In total, seven key statements from the focus group were gathered and analyzed using inter-rater reliability. These key statements are as follows:

1. "Still a huge amount of resistance… Green doesn't pay, green is too expensive. Still a lot of misconceptions."
2. "A lot of owners still think it is a costly endeavor, not necessary."
3. "There is an onerous perception that the money they are paying, there is no real value to that" (certification).
4. "Most of the time it comes down to dollars. There is a certification process with a fee associated. People think, 'Why should we pay for that if we don’t have to?' There is a huge organization that has been built over the last 20 years, that provides guidance that essentially you don't want to pay for it."
5. "Subcontractors are still resistant to implementing the LEED guidance."
6. "They hear stories from people throughout the industry. You submit all your points to USGBC. And they come back with petty little things to dispute it and there is a cost and it puts a bad taste in folks mouth because it is obvious that the

effort is there but there is this entity that says, if you want to argue with me its $500. So you are weighing this scorecard...should I do this or that?"

7. "USGBC is questioning things that work in the field… lots of negative questions about what is LEED, USGBC?"

All of the statements were rated as either very negative or slightly negative with respects to the question of “does this statement indicate that the industry professional has had a negative experience with sustainable construction.” All of the statements were rated as either very poor or slightly poor with regards to the questions of ”does this statement indicate that there is a poor perception of sustainable construction.

In addition to the statements that were rated using inter-rater reliability, a participant from the focus group gave additional insight into how LEED is perceived in the industry. He stated,

> *“They hear stories from people throughout the industry. You submit all your points to USGBC and they come back with petty little things to dispute it and there is a cost and it puts a bad taste in folk’s mouth because it is obvious that the effort is there, but there is this entity that says, if you want to argue with me its $500. So you are weighing this scorecard. Should I do this or that?”*

While this statement was not rated as to the type of perception that it indicates, it does provide additional insight into how industry professionals still view the LEED certification process. It is a very powerful description of the experience the project participants responsible for LEED certification have when actually trying to achieve certification. The findings from the focus group indicate that poor perception, driven by bad experience is still a barrier to sustainable construction.

The second barrier to sustainable construction is lack of experience. Several statements were gathered from the focus group that related to this issue. In total, three key statements from the focus group were gathered and analyzed using inter-rater reliability. The statements are in regards to the focus group participants dealings with the people actually implementing the project, i.e., the people that they managed. These key statements are as follows:

1. “Subcontractors are still resistant to implementing the LEED guidance.”
2. “There are still folks that do not have the resources, do not understand what you are asking.”
3. “They are very inexperienced with what the requirements are. We have enough problems just trying to get a normal submittal. It seems to be getting worse. Part of it is a lack of education and training. Another problem is they don’t have the manpower due to cost cutting.”

The statements were rated as to the level of experience indicated. The first statement earned a “no experience” and a “some experience” in the inter-rater reliability. The second two statements both were rated as ‘no experience.’ In addition to the statements that were rated using inter-rater reliability, a participant from the focus group gave additional insight into how LEED is perceived in the industry. When asked why there is still a lack of experience with sustainable construction, he stated, “These projects are just not that common, unless you do a lot of state work. Not everyone has been exposed to it [LEED requirement].” In fact, the focus group participants agreed that experience decreases the farther you get from metropolitan areas.

The third barrier to sustainable construction is current construction culture. Several statements were gathered from the focus group that related to this issue. In total, four key statements from the focus group were gathered and analyzed using inter-rater reliability. These key statements are as follows:

1. “Still a huge amount of resistance. Green doesn’t pay, green is too expensive. Still a lot of misconceptions.”
2. “Subcontractors are still resistant to implementing the LEED guidance.”
3. “You still have to wrangle them (subcontractors). VOCs, recycled content… it is just another layer of paperwork.”

4. "There are still folks that do not have the resources, do not understand what you are asking."

All of the statements were rated as either very negative or slightly negative with respects to the question of 'does this statement indicate that the industry professional has had a negative experience with sustainable construction.' All of the statements were rated as either very poor or slightly poor with regards to the questions of 'does this statement indicate that there is a poor perception of sustainable construction.

In conclusion, the findings from the focus group indicate that bad experience *does* give industry professionals a poor perception of constructing a sustainable project; industry professionals with limited experience with sustainable construction are *not* more likely to construct a sustainable project; and the findings also indicate that prevalence of conventional thinking *does not* encourage contractors to construct a sustainable project.

4.2.2. Construction Management Methods. While the objective of the focus group was to understand why barriers to sustainable construction still exist, the discussion also produced key insight as to potential successful management methods. As for this research, construction management methods will be validated using an industrial application (as first identified in Section 3 and to be detailed in Section 5); however the comments gleaned from the focus group were significant and warrant documentation. This section serves the purpose of documenting the important ideas related to management methods from the focus group.

The first remaining barrier to sustainable construction is bad perception. As previously identified in section 4.2.1 Existing Barriers to Sustainable Construction, bad perception of sustainable construction can be caused by prior bad experience with the process. Such bad experience can result in credits not being approved, and USGBC questioning and/or disputing the submitted documentation. This barrier can be overcome through concurrent documentation of the LEED requirements needed for certification. The members of the focus group agreed that some components to the LEED certification have become easier. For example, the materials required to earn certification are more readily available. A statement gathered from a participant in the focus group shed light on this issue. He stated "All suppliers push the green labels. A lot of changes have happened on the materials side. Even though some aspects, like the availability and identification of sustainable materials have become easier, the documentation is still difficult. A focus group participant stated that "it is the documentation of the process and we actually say what we have done is still the barrier."

Another focus group participant stated that "tracking incrementally is better because you catch a lot of stuff before submission." He elaborated that the only reason to not incrementally track the information needed for certification would be if you did not have adequate manpower. By catching mistakes or details that may not be in compliance with the standards needed to achieve certification *before* submission, the project team can overcome a situation where its work is disputed or rejected.

In addition to incremental documentation, early identification of LEED requirements was also identified by the focus group participants as a means to overcome the poor perception of sustainable construction. Early identification of the requirements allows the construction manager to get the 'buy-in' of the subcontractors. A focus group participant stated, "Incorporating the subcontractors in the LEED charrette, early on, to get their buy-in, has worked well. We just need to do that a little better on the construction part." The LEED charrette process is characteristic to design-build projects as a meeting held early on in the design process to establish overarching goals for the project that will be incorporated into the design; however this research is focused on design-bid-build projects. In order to translate a charrette from a design-build project, the same concept of early identification of requirements can be met by highlighting the requirements in the bid documents because that is the first interaction between the subcontractors and the construction manager in a design-bid-build project.

The second barrier previously identified was lack of experience. A focus group participant stated that with regards to subcontractors, "Trying to tune them into, this is what we want, this is what this means in the subcontract is a tough nut to crack, especially with less experienced subcontractors." This barrier can be overcome by having open communication channels that provide clear and timely expectations. One of the participants of the focus group had organized a LEED training class for all subcontractors, at no cost. As described by the participants of the focus group, it was very well received by all of the attendees. The class presented a lot of information related to LEED requirements and it was the first time many people had delved into the LEED concept. All of the focus group participants agreed that this was very beneficial to a construction project; however the benefit comes if the right people are at the training. For example, sending the project manager would not be prudent because he/she would not actually be doing the LEED tracking. The person attending the training should be the person doing the work, such as a project or field engineer.

In addition to the early-on communication, there also needs to be on-going communication throughout the duration of the project. The focus group participants agreed that there are effective means to accomplish this. These methods include displaying the LEED scorecard in a location where the subcontractors can see it, conducting regular field inspections, and processing submittals. These methods are utilized to communicate the expectations, compliance with the requirements, and corrective actions if compliance is not met.

The final barrier previously identified was current construction culture. The current construction culture is still resistant to implementing the LEED guidance and requirements. Much of the subcontractors' responsibility with regards to LEED certification is the submittal process. This process includes understanding and identifying the LEED requirements in the specification and then obtaining the correct materials that meet the specifications. The focus group participants agreed that it is difficult to get subcontractors that understand and are not resistant to the LEED requirements. One focus group participant stated that, "You are pushing them to provide [required submittals]. You might as well do it yourself." By standardizing the requirements and expectations, the construction manager is providing a roadmap for the subcontractors to follow.

4.3. SURVEY

As first identified in Section 3, the on-line survey was closed on with September 25, 2012, with 81 responses, reflecting an 8.5% response rate. The demographics of the respondents included 40.7% LEED Accredited Professionals, 70% have worked on a LEED certified project, and 18% have earned platinum level certification. The demographics of the survey respondents are summarized in Figure 4.5 Below:

Table 4.5 Survey Respondent Demographics

What is your area of expertise		
Answer Options	**Response Percent**	**Response Count**
Architecture/Engineer	46.9%	38
Construction	30.9%	25
Contract Administration	13.6%	11
Other, please specify	8.6%	7
Are you a LEED GA or LEED AP?		
Answer Options	**Response Percent**	**Response Count**
Yes	40.7%	33
No	59.3%	48
How many projects have you worked on that pursued LEED certification that did not (or have not) earned certification?		
Answer Options	**Response Percent**	**Response Count**
0	65.0%	52
1-5	22.5%	18
5-10	5.0%	4
10+	7.5%	6
What level of certification did the project(s) earn? (Check all that apply)		
Answer Options	**Response Percent**	**Response Count**
Certified	36.7%	18
Silver	61.2%	30
Gold	51.0%	25
Platinum	16.3%	8

The additional survey results will be discussed in the sections of this section as they relate to construction waste management, materials and resources, indoor air quality, and commissioning.

The survey respondents were asked “Would a standardized process for waste collection on a project site be helpful?” Table 4.6 below shows that fifty-six respondents answered the question on a five-point scale, ranging from not helpful to very helpful and six respondents answered the question ”Don’t know”.

Table 4.6 Survey Responses for Waste Collection

Would a standardized process for waste collection on a project site be helpful?							
Not helpful	Somewhat helpful	Neutral	Helpful	Very helpful	Don't know	Rating Average	Response Count
3	5	15	15	18	6	3.94	62

The survey responses were statistically analyzed using a Pearson’s Chi Squared test, in order to compare what the actual results were with what would have been expected (this test will be conducted for all survey questions). The results from the test are below in Table 4.7. The null hypothesis (H_0) for this survey question is a standardized process for waste collection would not be helpful on a project site. With a Chi Squared value of 22.4 and a degree of freedom of 5, the p value is less than .005. The α value is .1 (this value applies to all survey questions); therefore the null hypothesis is rejected and the alternate hypothesis is accepted that a standardized process for waste collection would be helpful on a project site with 90% confidence.

Table 4.7 Chi Squared Test for Survey Question 11

Survey Responses (Question 11: Would a standardized process for waste collection on a project site be helpful?)							
		Not Helpful	Somewhat Helpful	Neutral	Helpful	Very Helpful	Don't Know
Observed		3	5	15	15	18	6
Expected		9.333333333	9.333333333	9.333333	9.333333	9.333333333	9.3333333
Differences		-6.33333333	-4.333333333	5.666667	5.666667	8.666666667	-3.3333333
n	56						
(Differences)^2		40.11111111	18.77777778	32.11111	32.11111	75.11111111	11.111111
Diff^2 / Expected		4.297619048	2.011904762	3.440476	3.440476	8.047619048	1.1904762
Chi Square	22.42857						
k-1	5						

The survey respondents were asked "Would it be helpful to require subcontractors to itemize their materials with regards to LEED criteria in their bid?" Table 4.8 below shows fifty-eight respondents answered the question on a five-point scale, ranging from not helpful to very helpful and five respondents answered the question 'Don't know':

Table 4.8 Survey Responses for Materials & Resources

Would it be helpful to require subcontractors to itemize their materials with regards to LEED criteria in their bid?							
Not helpful	**Somewhat helpful**	**Neutral**	**Helpful**	**Very helpful**	**Don't know**	**Rating Average**	**Response Count**
8	7	14	14	15	5	3.57	63

The results from the test are below in Table 4.9. The null hypothesis (H_0) for this survey question is it would not be helpful to require subcontractors to itemize their materials with regards to LEED criteria in the bid. With a Chi Squared value of 10.1 and a degree of freedom of 5, the p value is less than .1. The null hypothesis is rejected and the alternate hypothesis is accepted that it would be helpful to require subcontractors to itemize their materials with regards to LEED criteria in the bid with 90% confidence.

Table 4.9 Chi Squared Test for Survey Question 15

Survey Responses (Question 15: Would it be helpful to require subcontractors to itemize their materials with regards to LEED criteria in their bid?)							
		Not Helpful	Somewhat Helpful	Neutral	Helpful	Very Helpful	Don't Know
Observed		8	7	14	14	15	5
Expected		9.666666667	9.666666667	9.666667	9.666667	9.666666667	9.6666667
Differences		-1.66666667	-2.666666667	4.333333	4.333333	5.333333333	-4.6666667
n	58						
(Differences)^2		2.777777778	7.111111111	18.77778	18.77778	28.44444444	21.777778
Diff^2 / Expected		0.287356322	0.735632184	1.942529	1.942529	2.942528736	2.2528736
Chi Square	10.10345						
k-1	5						

The survey respondents were asked "If you do not have a checklist that is used for IAQ (Indoor Air Quality) inspections, would a checklist be helpful?" Figure 4.10 below shows twenty respondents answered the question on a five-point scale, ranging from not helpful to very helpful:

Table 4.10 Survey Responses for Indoor Air Quality

If you answered no (do you have a checklist that is used for IAQ inspections), would a checklist be helpful?						
Not helpful	Somewhat helpful	Neutral	Helpful	Very helpful	Rating Average	Response Count
1	3	5	8	3	3.45	20

The results from the test are below in Table 4.7. The null hypothesis (H_0) for this survey question is a checklist for indoor air quality inspections would not be helpful. With a Chi Squared value of 12.4 and a degree of freedom of 5, the p value is less than

.05. The null hypothesis is rejected and the alternate hypothesis is accepted that it would be helpful to utilize a checklist for indoor air quality inspections with 90% confidence.

Table 4.11 Chi Squared Test for Survey Question 20

Survey Responses (Question 20: Would a checklist be helpful for indoor air quality inspections?)							
		Not Helpful	Somewhat Helpful	Neutral	Helpful	Very Helpful	Don't Know
Observed		1	3	5	8	3	0
Expected		3.333333333	3.333333333	3.333333	3.333333	3.333333333	3.3333333
Differences		-2.33333333	-0.333333333	1.666667	4.666667	-0.33333333	-3.3333333
n	20						
(Differences)^2		5.444444444	0.111111111	2.777778	21.77778	0.111111111	11.111111
Diff^2 / Expected		1.633333333	0.033333333	0.833333	6.533333	0.033333333	3.3333333
Chi Square	12.4						
k-1	5						

An open-ended question was asked to the survey participants: ‘How do you disseminate the commissioning plan to all applicable subcontractors?’ Forty responses were recorded but the answers were not adequate enough to complete a statistical analysis. Of the forty responses, 9 indicated that the commissioning plan was communicated through email, 8 indicated communication through meetings (commissioning, weekly, monthly, or kickoff meetings), and 9 indicated that it was the general contractor’s responsibility. There were two key statements that provide insight as to how the commissioning plan is communicated to the project team: 1) ‘Through project meetings and heavy coordination’, and 2) ‘Meet early, often with the architect, general contractor, owner, and commissioning agent to review the steps, expectations, and schedule.’

4.4. FINDINGS SUMMARY

This section presented the findings to both the survey and the focus group. The findings to the survey identified that construction management processes would be more helpful to sustainable projects with regards to waste management, materials and resources, indoor air quality, and commissioning. The findings from the focus group subsequently identified why barriers still exist on sustainable projects. The focus group also provided insight as to how these barriers may be overcome. The ideas were not validated in this section, but they were documented as part of this research because the concepts that were identified will be analyzed in the next two sections.

5. PROPOSED SOLUTIONS

The specific steps to implement the methods proposed for overcoming existing barriers and completing a successful sustainable construction project that will be explored in this section are as follows:

Construction Waste Management

- Step 1: Establish a contract clause for waste management for each subcontractor.
- Step 2: Hold a pre-construction meeting to discuss and illustrate the waste management plan for the project
- Step 3: Hold daily and monthly progress meetings and updates
- Step 4: Collection of construction waste on the project site

Materials and Resources

- Step 1: Bid breakout of materials
- Step 2: Submittal process
- Step 3: Record data and site verification

Indoor Air Quality

- During construction coordination: HVAC system protection, Containment source control, Pathway interruption, Housekeeping, Scheduling
- Before occupancy coordination: Flush out of the filtration system or Conduct an air test in accordance with the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air

Commissioning

- Step 1: Establishment and communication
- Step 2: Scheduling
- Step 3: Implementation and coordination

5.1. CONSTRUCTION WASTE MANAGEMENT

This section details the procedure for the construction waste materials management process and its development. The following construction manager's procedure for both preconstruction and during construction consists of four steps which include requests to make of the subcontractors, meetings to schedule, contractual clauses to include, and waste logistics was designated to maximize efficiency of sustainability construction waste management. These procedures occur primarily during the build phase of a design-bid-build project, but can start as early as the bid phase to ensure maximum effectiveness. Through a four-step process, the construction manager can effectively and efficiently ensure that the project delivery team[21] is able to meet all waste management criteria.

Construction waste is effectively generated throughout the project from inception to completion. The intent of construction waste management is to divert construction and demolition debris from disposal in landfills and incineration facilities. Further, waste management redirects recyclable recovered resources back to the manufacturing process and reusable materials to appropriate sites (USGBC, 2009).

The literature conducted in Section 2 identified that there are several methods for improving waste management on a construction project. In a 2009 study on indentifying and assessing factors for improving waste management performance on construction projects, 29 individual methods for improving waste management performance were organized in four sub-categories related to construction management (Cha, 2009). The study was limited because a) it was based on 57 responses from waste management practitioners on construction sites and b) the projects were not LEED certified, nor was there any sustainable criteria used to evaluate the projects. Of the 29 different construction waste management methods identified, 31% were related to subcontractor

[21] Define project delivery team

management and performance, 17% were related to the physical collection of waste, and 14% were related to tracking of waste and record keeping of the amounts and types of waste. The remaining methods were related to areas to design criteria or material selection. The methods are summarized below in Table 5.1 (Cha, 2009).

Table 5.1 Methods for Improving Waste Management Performance

Category	Method
Manpower	Commitment of contractor's representative at site
	Appointment of laborers solely for wastes disposal
	Cooperation of subcontractors
	Education of the contractor's staff (engineers)
	Education of subcontractor's staff (laborers)
	Preventing waste of materials by laborers
Materials and Equipment	Collecting packed materials back by suppliers
	Minimizing rework on a construction phase
	Design and construction using standardized materials
	Prefabrication of materials
	Use of recycled materials
	Preventing easily fragile materials from being used
	Minimizing loss of materials during carrying and storing
Construction Method	Setting up separated bins by waste type
	Sorting out individual waste by type from mixed wastes
	Designate a place for storing wastes in an early stage of construction
	Storing wastes at an easily accessible areas
	Preventing the ordering of excess materials
	Providing bins for collecting wastes for each subcontractor
	Installing equipments for recycling in a site
	Preventing mixing wastes with soil
	Installing an information board to notice categories for separating wastes
Management Practices	Contractual clauses for a subcontractor in dealing with wastes
	Positive incentive for decreasing or recycling by subcontractors
	Keeping a record about waste management (amount, kinds, etc)
	Shortening a period of collecting wastes in a site
	Contractual clauses about the methods for a waste disposal agency to treat wastes
	Establishing a waste management plan in an early state of construction
	Checklist on executing detailed waste management plan

While the study indicates that all of the above methods improve waste management processes, it is only the beginning of identifying improvements that can be made to construction waste management. The four-step process outlined above expands upon these methods for improvement by formulating a detailed plan for construction managers to be enacted on a LEED certified project to achieve measurable results.

Further literature in Section 2 identified that when no one construction manager is responsible to manage waste, the project team will be less likely to have an effective waste management plan. This conclusion was reached upon the close analysis of a case study on a non-LEED certified project (Ilozor, 2009). Both the Cha and Ilozor studies have identified the importance of a detailed and comprehensive waste management plan to the success of a construction project. Haselbach (2008) also identified a need to optimize construction practices to facilitate construction and demolition debris.

5.1.1. Proposed Construction Waste Management Plan. Step 1: Establish a contract clause for waste management for each subcontractor. The owner typically has a contract clause with its prime contractor, but it is not typically passed on to the subcontractors. A clause in the contract regarding the expectations and requirements will keep the subcontractors fiscally accountable and will reduce any misunderstandings amongst the multiple subcontractors. It is important that this be included in the bid estimate because this is the first construction manager-to-subcontractor involvement on a design-bid-build project. The earlier that the construction manager can influence the subcontractor with regards to waste management, especially with one that has little to no experience with waste management on a LEED project, it is more likely that the subcontractor will be educated and exposed to the LEED requirements. The contract clause shall include the type of materials to be collected, the duration for collection, and the method of collection (method of collection will be discussed in Step 5: Collection of

Construction Waste). An example of how the clause should read is as follows in Table 5.2.

Table 5.2 Example Waste Management Clause

<u>Overview</u> The waste management plan is based on the requirements of LEED New Construction 2009 credits Materials & Resources 2.1 and 2.2. The project's goal is to divert at least 75% of construction and demolition from landfills and incinerators, redirect recyclable recovered resources back to the manufacturing process, and usable materials to the appropriate site, as outlined in LEED NC 2009 Reference Guide dated June 2010. The implementation of this plan is critical to the success of the Project's environmental and sustainability goals. <u>Recyclable Materials</u> The following is a list of the construction and demolition waste materials that shall be diverted where applicable: a. Concrete b. Wood c. Cardboard, plastics, and paper d. Scrap metal e. Gypsum board f. Mixed paper (from packaging) g. Aluminum can and plastic bottles <u>Collection of Waste</u> Throughout the duration of the project, each subcontractor will be responsible for the appropriate disposal of their waste. Construction demolition and waste will be collected and managed in two ways at the job site: 1) waste will be disposed on site through collection containers located at each layout area, and 2) waste will be hauled directly off site upon it creation. <u>Tracking and Monitoring</u> All waste created during the project will be consistently monitored and tracked. For all waste collected on site, the waste diversion company will submit tracking logs. Waste receipt tickets and non-hazardous solid waste diversion reports shall be submitted on a monthly basis and kept on file throughout the project. The breakdown by weight (measured by tons) of which material type disposed of as follows is required in the tracking form: a. Recycling; broken down by material type b. Salvage; including reuse on site c. Hazardous waste disposal All subcontractors, their employees and vendors, will be trained to ensure this plan is implemented correctly.

Step 2: Hold a pre-construction meeting to discuss and illustrate the waste management plan for the project. The construction manager shall conduct a pre-

construction meeting that is mandatory for all subcontractors. The meeting should be held prior to subcontractors gaining access to the construction site. While it is ideal to have representative from all the subcontractors that will be working on the project, it is not realistic because not all subcontractors have the same scope of work or duration of work; therefore, this meeting cannot be held just one time at the beginning of construction. Subsequent meetings will be needed as new subcontractors start their work on site. At the meeting, the construction manager shall review its overall waste management plan. The construction manager shall NOT just read from its plan; they should have the labeling for the collection containers available and the location of the containers. The meeting should be held as a site-walk so the subcontractors can see where they will be collecting their waste. A sample agenda should include the follow points:

1. Materials to be collected
2. Method of collection
3. Location of bins (with site diagram)
4. Timing of collection
5. Percent (%) of diversion
6. Incentives
7. POCs

Step 3: Hold daily and monthly progress meetings & updates. Tool box meetings[22] are held daily to discuss safety and the work to be completed that day. Included in these meetings should be a discussion of what material needs to be collected. These meetings are so vital because they are directly addressed to the construction workers in the field; however LEED requirements and updates are not normally covered

[22] A tool box meeting is a daily meeting between a field supervisor and the workers to go over the daily work to include and safety concerns and specific tasks for the day.

in these meetings. The monthly meetings shall include the foreman and quality control staff to review diversion percentages. The construction manager or superintendent shall present the diversion percentages to the group so there is an understanding of how the project is progressing towards its goal. The construction manager shall be responsible for collecting and recording the diversion percentages on a monthly basis through the life of the project. A sample agenda of topics to be covered in the monthly meeting would update the topics discussed in the pre-construction meeting and include:

1. Materials to be collected
2. Method of collection
3. Location of bins (with site diagram)
4. Timing of collection
5. % of diversion
6. Incentives
7. Points of Contact (POCs)

Step 4: Collection of construction waste on the project site. The construction manager shall identify which materials are to be collected for diversion. This usually includes concrete and masonry, metals, woods, plastic, drywall, and cardboard as the materials to be collected, at a minimum. These materials make up over 75% of the waste generated on construction projects (Ilozor, 2009). These materials are also recommended for consideration by USGBC to be diverted. The waste containers must be easily accessible and clearly marked in order for subcontractors to understand what is expected of them. The location of the collection point is important to both the subcontractors and the hauling agency for maximum efficiency of vehicle traffic. The location will be site specific and the rate of collection will be in relation to the rate of construction. Both of these factors shall be determined by the site project manager and superintendent prior to start of construction.

5.2. MATERIALS AND RESOURCES

This section details the procedure for material and resource selection and procurement and its development. The following construction manager's procedure for both preconstruction and during consists of three steps which include bid requirements, submittal review and approval, and recording and verification of data.

Through a three-step process, the construction manager can effectively and efficiently ensure that the project delivery team is able to meet all material and resource criteria needed to achieve LEED materials and resources and/or indoor environmental quality credits. This three-step process encompasses both LEED sections materials and resources (MR) and indoor environmental quality (IEQ) because both facets have similar components that pertain to the step detailed below. This includes compliance with the following criteria:

1. Building reuse (MR)
2. Materials reuse (MR)
3. Recycled content (MR)
4. Regional materials (MR)
5. Rapidly renewable materials (MR)
6. Certified wood (MR)
7. Low-emitting materials: adhesives and sealants, paints and coatings, flooring systems, and composite wood and agrifiber products (IEQ)

As first discussed in Section 2, each sustainable project has to place emphasis on appropriate selection of materials (Yudelson, 2009). The research conducted in Section 2 identified that improper on-site management and planning can cause delays in passing information on types and sizes of materials and components to be used on the project (Glass, 2008). In addition, all material submittals have been identified as construction submittals (as opposed to design submittals); therefore, it is the responsibility of the construction manager to ensure that the submittals are not only timely, but also in accordance with the LEED criteria for point acceptance. Unless the materials are documented through the construction of the project, they may not be able to be verified from the preconstruction documents or the build project (Haselbach, 2008).

There are so many different types and uses of materials that go into a building, and they have vastly different values based on weight, cost, or application. Therefore, to determine percentages of materials usages, it is important to define which materials are included in the calculations and what units the calculations are based on (Haselbach, 2008). There are additional documentation requirements when a project has a goal of demonstrating compliance with LEED criteria related to sustainable materials and resources (Langdon, 2007). Without the proper process for procurement and verification, it can be difficult to ensure that the materials are delivered on site with no impact to the project schedule, while at the same time confirming that the materials are in compliance with LEED requirements. Project teams often find it useful to construct a spreadsheet matrix listing materials against the environmental criteria being considered so that materials options can be compared in a simple format (Reed, 2008).

5.2.1. Proposed Materials and Resources Management Plan. Step 1: Bid breakout of materials. The construction manager shall request itemization of sustainable materials in the bid to include material name and description, location, and availability. Detailing the materials will assist the construction manager to ensure that the subcontractor has accounted for the ability and timeliness of procuring potentially specialized materials in time and in accordance with the contract requirements. Requiring the materials to be itemized in the bid will also allow the construction manager to have an early identification of which subcontractors are aware of the LEED requirements, as opposed to low-bid or inexperienced subcontractors that may not understand what is expected on a LEED certified project.

Step 2: Submittal process. The construction manager shall require that all subcontractors have approval on its submittals prior to installation of the given material. Prior review and approval will identify potential issues before they become problems that can adversely affect the cost, quality, schedule, or ability to achieve LEED certification for the project. The construction manager shall review the project specification in order to make a comprehensive submittal register to be used on the project. This will assist in producing a clear path from material selection to procurement, and ultimately installation.

Step 3: Record data and site verification. The construction manager shall perform regular site visits to verify that the correct material is being installed. A typical itinerary of the site visit includes observing and recording progress of construction, safety compliance, and overall quality assurance that the install and construction is in compliance with the contract specifications. On a sustainable construction project, a site visit will also include the additional step of inspecting material installation to ensure compliance with LEED requirements.

The timing of the site visits should correlate to the type and amount of construction occurring on the project. As the rate of placement is high, the construction manager may be required to visit the site more frequently. As a rule of thumb, site visits should occur daily. The construction manager shall also record all material related to credit compliance in order to verify the LEED requirements to include percentages of reused materials, recycled content, regional and rapidly renewable materials, and VOC content. Recording of the material data should be completed incrementally, as opposed to all at once towards project completion. The construction manager shall typically include the following information on a comprehensive spreadsheet[23]:

1. Subcontractor
2. Product/Material description
3. Manufacturer/supplier
4. Overall product cost
5. Percent and value of reused material
6. Percent and value of post consumer and post industrial (for recycled materials)
7. Location
8. FSC Certified wood
9. VOC content

Table 5.3 below illustrates a sample spreadsheet[24]:

[23] Data associated with Materials & Resources Credit 1 Building Reuse is typically captured on a separate spreadsheet because it entails unrelated data.
[24] The sample spreadsheet has been transposed for clarity within the text.

Table 5.3 Materials & Resources Spreadsheet

Overall Product Data	Subcontractor
	Product / Material Description
	Product Supplier / Distributor
	Product Manafacture
	Overall Material Cost
MR Credit 3 Materials Reuse	% Reused Material
	Cost of Reused Material
MR Credits 4 Recycled Content	% Post Consumer
	Post Consumer Value
	% Post Industrial
	Post Industrial Value
	Recycled Content Information Source
MR Credit 5 Regional Materials	Distance to Manufacturer in Miles
	Location
	Distance to Extraction Site
	Regional Content Information Source
	Value Percentage
	Value towards Regional Materials
MR Credit 6 Rapidly Renewable	% Rapidly Renewable Content
	Value of Rapidly Renewable Content
MR Credit 7 Certified Wood	Value of Certified Wood
	Certified Wood (by Weight)
	FSC Chain-of-Custody Number
IEQ Credit 4	VOC Content
	Urea Formaldehyde Content

In addition, verification of installation shall be captured through photographs. Photographs should be taken by the superintendent and construction manager at a minimum. Any project supervision should be authorized to take photographs, but the construction manager is ultimately responsible for categorizing and organizing the photographs. Once the majority of the submittals have been submitted for review and then reviewed and approved by the construction manager, the construction manager will have more time and resources to adequately and thoroughly conduct site visits for verification of installation of the correct materials to meet the LEED requirements.

5.3. INDOOR AIR QUALITY PROCESS

This section details the procedure for indoor air quality management and its development. The following construction manager's procedure consists of two steps which include creating and implementing a thorough plan and communicating it to all applicable subcontractors during construction (step one) and prior to occupancy (step two). The two-step process outlined below expands upon these methods for improvement by formulating a detailed plan for construction managers to be enacted on a LEED certified project to achieve measurable results.

Indoor air quality is defined as the nature of air inside the space that affects the health and well-being of building occupants (Haselbach, 2008). During construction, there are three primary areas of concern for indoor air quality (Kibert, 2008):

- Storage of materials to prevent moisture and contaminant exposure
- Protection of HVAC system components prior to installation
- Protection of installed HVAC systems from contamination during construction

Activities during construction can have an impact on the indoor air quality of portions of buildings that are occupied during the construction phase and on the indoor air quality of the entire building after construction (Haselbach, 2008). Such activities include delivery and storage of materials, and installation of HVAC systems. USGBC provides different methods for reducing indoor air quality problems from the construction process for the betterment of the construction workers and the building occupants: HVAC protection, source control, pathway interruption, housekeeping, and scheduling (USGBC, 2009).

Once construction is complete, indoor air quality is also tracked prior to occupancy with the intent "to reduce indoor air quality problems resulting from construction or renovation to promote the comfort and well-being of… building occupants" (USGBC, 2009). There are two specific options that a project may choose to conform to the requirement: flush-out of the building's ventilation system, or conduct a baseline air test after construction ends and prior to occupancy (USGBC, 2009). The selection may be dictated by the contract documents from the owner and/or designer, or the choice may be left to the construction manager.

5.3.1. Proposed Indoor Air Quality Management Plan. Step 1: During Construction. The construction manager shall create and implement a written plan that includes the following sections:

1. HVAC System Protection
2. Containment Source Control
3. Pathway Interruption
4. Housekeeping
5. Scheduling

These five criteria are necessary because they "meet or exceed the recommended control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings Under Construction", as required by USGBC (USGBC, 2009).

This plan shall identify the subcontractors that are responsible for implementation on the project, according to their scope of work. The plan will include a checklist of requirements to standardize the requirements for the subcontractors. An example checklist is as follows:

HVAC System Protection

HVAC System Not in Use

- ❑ Mechanical Rooms are not being used for storage of construction or waste materials
- ❑ All HVAC Equipment is sealed and protected
- ❑ Ductwork awaiting installation is sealed against contaminants
- ❑ Installed ductwork is sealed (no open ends)
- ❑ Installed supply diffusers are sealed
- ❑ Installed return openings are sealed

HVAC System in Use

- ❑ MERV 13 filtration for supply air intakes
- ❑ MERV 18 filters at return air openings
- ❑ Ductwork inspection
- ❑ No contamination found
- ❑ Contamination found – requested duct cleaning – location: _____________
- ❑ Duct cleaning completed – location: ________________

In addition to the checklist, designated responsible subcontractors and/or the construction manager shall document the observations with photographs taken during the inspections performed with the checklist. The photographs are necessary to comply with USGBC requirements "to maintain a detailed photo log of the construction IAQ management plan practices followed during construction." The photographs shall be compiled and maintained by the construction manager.

Step 2: Before Occupancy. If the option is not dictated in the contract documents from the owner and/or designer, the construction manager must decide to either conduct a 1) flush-out of the filtration system, or 2) conduct an air test in accordance with the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air. If the quality of the air is high enough to comply with the EPA air test, that option will save the project time and effort. If the air quality is not in compliance with EPA standards, it will be necessary for the construction manager to choose the flush-out option. This will require additional scheduling and coordination because the flush-out can only begin after all construction work, including punch-list items, is complete.

5.4. COMMISSIONING

This section details the procedure for management of the commissioning process on a LEED certified project and its development. The following construction manager's procedure for both preconstruction and during consists of three steps which include establishing a commissioning plan and distributing to all necessary parties, scheduling of the commissioning activities into the project schedule, and supervision and implementation to maximize efficiency of sustainability construction commissioning in accordance with the LEED requirements.

Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the owner's project requirements (Haselbach, 2009). The construction manager should have the scheduling and construction background necessary to supervise a commissioning agent (Oregon Office of Energy, 1997). Ideally, such experience shall include work on a previous job of similar scope and size that achieved LEED certification. The literature in Section 2 identified that the construction manager is responsible for gathering information for review by the project team and facilitating the commissioning schedule by coordinating activities with owner representatives and subcontractors (Oregon Office of Energy, 1997); however, a follow on step of dissemination and communication of the commissioning plan and requirements to the project team must also occur.

5.4.1. Proposed Commissioning Management Plan. Step 1: Establishment and Communication. Establishment of the commissioning plan is the commissioning agent's responsibility, but the communication is the construction manager's responsibility. Once the plan is established by the commissioning agent, it must be communicated to all applicable subcontractors, particularly the electrical, mechanical, and building envelope subcontracts, and any other project stakeholders that may influence the implementation of the plan, namely the owner. Communication of the plan shall occur through a commissioning kick-off meeting to review the expectations and requirements, with follow-up meeting held monthly to review and updates to the plan as well as interim progress. The meetings should be monthly until the execution of the commissioning activities, at which time the meeting will become weekly or daily, depending on the scope of the commissioning effort. If there are commissioning activities occurring daily, then the meetings need to be daily as well.

Step 2: Scheduling. The construction manager shall include the commissioning agent in the initial schedule development common to every well-managed project. This will ensure that the commissioning agent has had the ability to give his or her input as to how commissioning is integrated into the project schedule. It will also ensure that time is given to commission the building properly and in accordance the commissioning agent's plan and the owner's project requirements. All levels of commissioning activities shall be added to the schedule as immediate successors to the related construction activity.

Step 3: Implementation & Coordination. The construction manager shall ensure that all applicable subcontractors and owner representatives are aware of the plan by holding a weekly commissioning meeting to disseminate information and coordinate action for the upcoming week. If there are commissioning activities occurring daily, then the meetings need to be daily as well. This will allow the project to identify and address all issues that may otherwise affect the quality and schedule of the project. The commissioning meeting can be held in conjunction with the weekly Owner-Architect-Construction Management Meeting, or as a separate meeting. The necessary information to be covered is as follows:

1. Testing that occurring over the past week: did the test pass or fail?
2. If the test failed, what is the plan for corrective action
3. Upcoming tests to be completed: date and time
4. Testing criteria
5. Required personnel to perform and observe testing
6. Dissemination of testing results

5.5. SUMMARY

Kibert (2008) states that “perhaps the most important group in a building construction project is the subcontractors. All subcontractors should have input to the plan to make it effective… the buy-in of the subcontractors is key to successfully minimizing waste.” Throughout the four facets of managing a sustainable construction project, i.e., construction waste management, materials and resources, indoor air quality, and commissioning, the detailed process from Section 3 requires the construction manager to incorporate the subcontractors at nearly every step.

The construction management process detailed in this section will facilitate obtaining the LEED credits that the construction manager is responsible. The construction manager is responsible for up to 50% of points needed for LEED compliance. Table 5.5 summarizes these 18 construction management credits, with a total of 20 possible points:

Table 5.4 Construction Management Point for LEED Certification

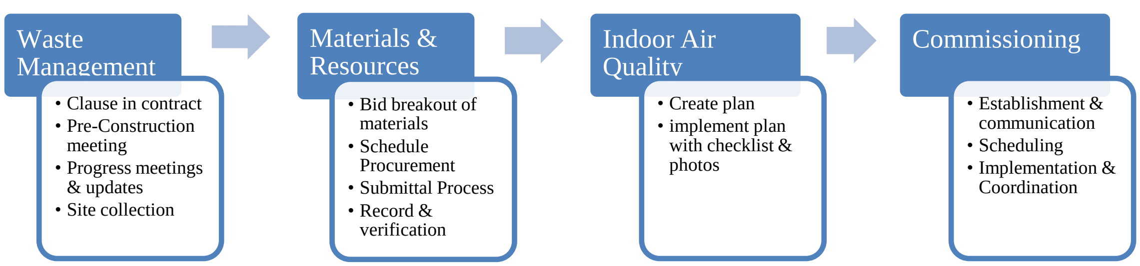
Credit		**Possible Points**
	SS Prerequisite 1 Construction Activity Pollution Prevention	
1	SS 5.1 Site Development: Protect or Restore Habitat	1
2	EA Prerequisite 1 Fundamental Commissioning of Building Energy Systems	
3	EA 3 Enhanced Commissioning[25]	2
4	MR 2 Construction Waste Management	3
5	MR 3 Materials Reuse	2
6	MR 4 Recycled Content	2
7	MR 5 Regional Materials	2
8	MR 6 Rapidly Renewable Materials	1
9	MR 7 Certified Wood	1
10	IEQ 3.1 Construction IAQ Management Plan – During Construction	1
11	IEQ 3.2 Construction IAQ Management Plan – Before Occupancy	1
12	IEQ 4.1 Low-Emitting Materials – Adhesives and Sealants	1
13	IEQ 4.2 Low-Emitting Materials – Paints and Sealants	1
14	IEQ 4.3 Low-Emitting Materials – Flooring Systems	1
15	IEQ 4.4 Low-Emitting Materials – Composite Wood and Agrifiber Products	1
	Total Points	20

[25] Commissioning is typically the responsibility of an independent Commissioning Agent; however, commissioning occurs during construction and requires coordination with the construction manager.

A LEED certified building requires a minimum of 40 points; construction management comprises nearly half of the points needed. The highest level of certification, platinum, requires 80 points. Even at the most ambitious certification level, construction management affects almost 25% of points needed for certification.

Currently, many contractors are determining their management processes for sustainable construction from on-the-job training. The knowledge that a construction manager gains often times stays with that person and does not get passed along. This perpetuates the barriers to sustainable construction because rather that identifying and overcoming the barriers, the barriers are assumed to be an unavoidable part of sustainable construction. The construction management practices proposed in this section can standardize the unknown and make it understandable. Table 5.5 below depicts a chart that can be used to summarize the construction management methods proposed to overcome the barriers to sustainable construction:

Table 5.5 Flow Chart of Sustainable Construction Management Processes



This section identified the sustainable construction management process that can overcome the barriers to sustainable construction. The following section will detail the findings related to the industrial application as to how the management methods proposed in this section can be implemented to overcome the barriers to sustainable construction.

6. VERIFICATION OF PROPOSED SOLUTIONS THROUGH AN INDUSTRIAL APPLICATION

A thorough analysis of a sustainable construction project (industrial application) will indicate that the detailed construction management processes presented in this dissertation, including areas of waste management, material procurement, indoor air quality, and commissioning, can be applied to the bid and build phases of a sustainable construction project to overcome the existing barriers to sustainable construction.

The barriers that have been previously identified in this research, perception, lack of experience, and current construction culture, can be overcome by documentation, early identification of costs and requirements in the bid, communication, and standardization.

6.1. PROJECT BACKGROUND

Utah Valley University (UVU) is the second-largest four-year institution in the Utah System of Higher Education. UVU currently has more than 28,000 students. The UVU mission statement is as follows:

> *Utah Valley University is a teaching institution which provides opportunity, promotes student success, and meets regional educational needs. UVU builds on a foundation of substantive scholarly and creative work to foster engaged learning. The university prepares professionally competent people of integrity who, as lifelong learners and leaders, serve as stewards of a globally interdependent community.*

The Utah Valley University New Science Building was a new construction project needed by UVU to accommodate the university's growing student population. In 2010, UVU had 33,000 students, making it the largest university in the state of Utah. Growth projection for the university is 40,000 students by 2020. In the spring of 2010, the state of Utah approved $45 million in funding for a new science building. The facility was one of Utah's top building projects heading into the 2010 legislative session due to UVU's severe space constraints. The university was serving its growing populations with the fewest square feet per student (121.5) among all institutions in the Utah System of Higher Education. The UVU science building would provide an additional 160,000 square feet to the campus, including 27 labs, 12 classrooms and a 400-seat auditorium. The scope of the new construction project was:

> *A three-story building plus roof-top mechanical penthouse consisting of approximately 160,000 square feet. The building will contain classrooms, lecture rooms, and auditorium, faculty offices and laboratories and support spaces for teaching general biology, botany, microscopy, physics, zoology, microbiology, anatomy, physiology, and earth science.*

Construction occurred from September 2010 until project completion in March 2012. The value of the project at award was $30 million, with an additional two million in changes that occurred after award, for a total project value of $32 million. The owner of the project, the Division of Facilities Construction and Management (DFCM) specified that the building would meet LEED silver standards. Table 6.1 below is a list of the project participants that will be referenced repeatedly throughout this research.

Table 6.1 Project Participants

Title	Role
Owner (Division of Facilities Construction and Management)	A state government agency in Utah that oversees construction projects and provides the funding for the project.
End User (Utah Valley University)	The end user of the New Science Building project.
Construction Manager (Big-D Construction)	Construction company under contract with the owner as the prime contractor to coordinate all subcontractor work and to complete all construction in the given time period and budget.
Architect (GSBS Architects)	Designer of the project hired by the owner.
Project Manager	Person designated as the manager of the project on behalf of the construction manager. Responsible for completing all construction in the given time period and budget.
Field Engineer	Person designated on behalf of the construction manager as the primary responsible party to manage the day-to-day operations of the project, including coordinating all subcontractor work.
Superintendent	Person designated by the construction manager to oversee and supervise all construction activities and craft personnel.
Commissioning Agent (Utah New Vision Construction LLC)	Hired by the owner and responsible for ensuring the final construction project meets the owner's requirements, specifically the mechanical, electrical and building envelope systems.

The Utah Valley University New Science Building first received funding for design and construction in 2008 from the Utah state agency, Division of Facilities Construction and Management. The DFCM is the building manager for all state owned facilities and is responsible for:

- All aspects of construction and maintenance of state buildings
- Assisting the Utah State Building Board in developing its recommendations for capital development project and capital improvement funds
- Controlling the allocation of state owned space

The DFCM also manages the contingency funding and allocates it to the project as necessary. For example, all contract change orders are allocated through the DFCM. The DFCM set the budget for the UVU New Science Building, with input from the university, and issued the funding to the university to complete the project. The UVU representative for the construction of the New Science Building, Mr. Frank Young, stated that:

> *We don't have a clear picture of the final costs. We estimate that the LEED Silver will make a difference of around $ 60,000.00. Most of the cost is in the extra record keeping and verification time that the architects spend in making sure we get full credit for the points we submit.*

The architect developed the UVU New Science Building Addition Program. The program was a broad description of the specific considerations and requirements that the university wanted in the finished product. It was developed prior to the plans and specifications. The program outlined the concept of the building and included all sustainable considerations that were to be included in the building. The sustainable considerations began as followed:

> *The State of Utah recently adopted LEED Silver certification as the standard for all new state funded construction. The sustainability goal for this design will be to achieve a LEED Silver rating. LEED version 3 is now the standard, also called LEED 2009.*

The program continued on to list all reasonable sustainable considerations and strategies to be included in the design and construction of the building:

1. Does site selection meet the LEED criteria?
2. No new parking
3. Shower accommodations and bicycle racks for occupants with showers no more than 200 yards from the facility. Consider the Physical Education facilities as showers for bicycle commuters.[26]
4. Proximity to bus stops for campus and city transit systems
5. Landscape design that restores habitat
6. Open space considerations
7. Reduce heat island effects for both the site paving and the roof
8. Light pollution reduction

[26] Physical Education facilities

9. Design a water efficient landscape around the building and consider how the campus wide irrigation system figures into water use reduction strategies
10. Utilize water efficient fixtures to reduce water consumption
11. The greatest potential for improving the sustainable performance of the building is reflected in the new LEED standards for energy efficiency. Given the high volume of air needed within the lab facilities, it will be a challenge and goal to achieve a high level of energy efficiency within the HVAC and electrical systems of the building.
12. The State mandates enhanced commissioning therefore the two points for this item can be added to the total score.
13. Enhance refrigerant management should be a given
14. With its Utah County location and proximity to recycling centers, a construction waste management program should be mandated
15. Recycled content, Regional materials, rapidly renewable resources, and certified wood products should be achievable points.
16. Increased building ventilation may be a possibility with the increased air flow required by the lab spaces.
17. Both construction and pre-occupancy indoor air quality programs should be instituted.
18. Low emitting products of all types should be the norm for the project
19. Controllability of lighting and thermal comfort should be possibilities as well as thermal comfort verification.
20. Day lighting and views for occupied spaces seems like a reasonable goal given the request for maximum amounts of natural light throughout the new addition.

The program to itemize specific issues that should be considered when planning the project:

- In all of the strategies to achieve a LEED Rating, the true goal of sustainability – reducing the impact our built environment has on the natural world – should not be lost.
- The State and UVU Facilities are extremely interested in constructing a building that has significantly lower life cycle operation costs as well as lower life cycle maintenance cost. This may require that first costs be a bit higher in order to achieve try life cycle benefits.
- It will be important for the building to incorporate principles of passive solar design.
- Discussions with the campus have revealed that, while a vegetated roof can be a worthy goal, their preference is to avoid the maintenance problems that may be associated with a roof top landscape.

- Considerations might be given to using photovoltaic panels to generate renewable energy for the project and for the campus. Such systems would be valuable as demonstration modules or displays. However, full electrical production for the building of the campus is not compatible with current campus electrical systems.

The contract delivery method for the project was design-bid-build. The construction manager for the UVU New Science Building was Big-D Construction, based in Salt Lake City, Utah. They received the project documents and drawings on May 7th, 2010 in order to prepare the bid. Big-D submitted its bid in June 2010. From May to June, the bid preparation consisted of the construction manager preparing a cost estimate on the scope of work in the project documents, and subsequently waiting until the day before the final bid was due for the subcontractor bids to be submitted. The estimator for Big-D was a LEED AP, but his experience with LEED criteria was under-utilized. His responsibility was to review the bid for cost requirements. In essence, this process left no time for project integration between the construction manager and the subcontractors that would be awarded the contract. This is common practice in the industry and it is a problem because it leaves little time for the leadership of the project to become knowledgeable about the project details and requirements. After bids were submitted and reviewed by the university, the project was awarded in July to Bid-D Construction.

According to the university representative, between June and August, there were some issues with the funding that slightly delayed the start of the project. This extra time gave the construction manager increased time to review the plans and specifications. According the field engineer, this extra time to understand the project documents was “kind of rare”, but also beneficial because the bid process did not lend itself to a comprehensive review of the information. The extra time provided by the delay in funding allowed the construction manager the ability to digest the project requirements in a way that was not possible during the bid process. There was also one site walk after award, but before mobilization which helped the project team with the job logistics, i.e., setting up the project site and trailers. The subcontractors were invited to attend. Project management for Big-D mobilized to the site on August 1, 2010. The construction permit allowed construction to start on September 19, 2010.

The field engineer first got to review the plans and specifications in the middle of July 2010, after the contract was awarded to Big-D Construction. The project superintendent looked at the plans and specifications for a total of 40 hours before the bid was submitted. He was also able to conduct a site visit to become more familiar with the project requirements. The site visit also helped the superintendent with the logistics, i.e., the trailer set up, parking for the work force, and site access. Within 24 hours of submitting its bid to the owner, Big-D was required to submit a list of its subcontractors that it planned to use on the project. These subcontractors had only submitted their bids to Bid-D in the previous 48 hours, before the bid was due to the owner. This only allowed for very minimal coordination between the project manager and its subcontractors. There were 40 subcontractors working for the construction manager on the UVU New Science Building. The subcontractors were only exposed to the overall scope of the project, with little time for the details. The field engineer stated, “When I get the submittals, it is pretty clear who understood LEED in the bid documents.” He also indicated that many of the subcontractors do not understand the LEED requirements, even if it is highlighted in the bid documents. It is not until the construction manager places emphasis on the requirements that the subcontractors begin to comprehend what is required of them.

After the project was awarded, there was one site orientation with the subcontractors before mobilization.[27] Although no meeting minutes were kept, the field engineer recalled that the meeting was approximately an hour and a half long and attendance included all subcontractors affected by the LEED requirements. The project manager observed that the subcontractor representatives at the LEED kick-off meeting were not very engaged and did not ask questions. The first documented discussion on the LEED requirements between the construction manager and the subcontractors occurred on December 14, 2010 during the commissioning kick-off meeting. The meeting was run by the construction manager and the architect was not in attendance. LEED requirements was a topic on the agenda. Table 6.2 lists the LEED-related items covered in the meeting, according to the field engineer in attendance, as well as the corresponding LEED credit:

[27] There was time for a site orientation because of the delay in the funding. If there had not been a delay, there would not have been time for the orientation. This would have left the subcontractors with even less time to become familiar with the project requirements.

Table 6.2 Agenda for the Kick-Off Meeting with Corresponding LEED Credit

Topic in Meeting Agenda	**Corresponding LEED Credit**
VOCs: A list of VOCs in the specifications was distributed to the foreman of the subcontractors.	Indoor Environmental Quality 4.1: Low Emitting Materials – Adhesives and Sealants, 4.2 Low Emitting Materials – Paints and Coatings, 4.3 Low Emitting Materials – Flooring System, 4.4 Low Emitting Materials – Composite Wood and Agrifiber Products
Air quality	IEQ 3.1: Construction Indoor Air Quality Management Plan – During Construction
No smoking/food in the building	IEQ 3.1: Construction Indoor Air Quality Management Plan – During Construction
No fumes in the building	IEQ 3.1: Construction Indoor Air Quality Management Plan – During Construction
Welding standoff from the building	IEQ 3.1: Construction Indoor Air Quality Management Plan – During Construction
Adhesives in the building	IEQ 3.1: Construction Indoor Air Quality Management Plan – During Construction, 4.1: Low Emitting Materials – Adhesives and Sealants,

As a follow up to the LEED kick-off meeting, the Owner, Architect, Contractor (OAC) meetings continued to address air quality, VOCs, and eliminating food and drink from the building. This was a weekly meeting to discuss the issues on the project. During the 19 month duration of the project, 80 OAC meetings were held. Each on-site subcontractor sent a representative to the weekly meeting. Also in attendance were an average of 10 owner’s representatives and/or end users, and two architects.

6.1.1. Analysis and Findings from the UVU Industrial Application.

Existing Barriers to Sustainable Construction. Perception as a barrier to sustainable construction was previously tested in Section 4. It was determined that perception is a barrier to sustainable construction. The findings from the industrial application support these findings and enhance the understanding as to how perception affects a sustainable construction project.

The field engineer had several key observations when discussing how sustainable construction was perceived by the workers on the project. When asked about how the subcontractors performed on the project, the field engineer stated:

1. "Unfortunately, it seems these guys are just used to being told what to do. It's sad there's not much collaboration."
2. "The home office is pretty knowledgeable but the field guys only care about production."
3. "Some of the guys think they know about LEED, but they don't. I wish more subcontractors knew about it.
4. Many subcontractors treated it like "a joke". The field engineer had to continuously stress the importance of meeting the LEED requirements to the subcontractors.

These observations were made throughout the project, but they were most prevalent towards the beginning of the project when the field engineer first became acquainted with the subcontractors that would construction the project. There is a commonality within the observations and statements made by the field engineer that the subcontractors did not place any value on the sustainability requirements of the project. They came into the project with a perception that LEED was "a joke" and something that got in the way of production.

With regards to the issue of the perception of the high cost of sustainable construction, there were several significant findings from the UVU New Science Building industrial application. The issue of cost was apparent from the beginning of the project, when it was first under development from the owner. From the genesis of the project, the owner's representative had budgeted $60,000 for the cost of obtaining LEED silver certification. The initial award value of the project was $30 million, only .2% of the entire project value. The owner's representative stated that:

> *"We don't have a clear picture of the final costs. We estimate that the LEED Silver will make a difference of around $ 60,000.00. Most of the cost is in the extra record keeping and verification time that the architects spend in making sure we get full credit for the points we submit."*

This very small value, especially as a percentage of the overall project, is evidence that cost is not significant when constructing a LEED project (at the silver level of certification). There is a dichotomy between the low cost that the owner placed on LEED certification and the high cost that industry professionals believe to be associated with sustainable construction, as evidenced in the focus group. This difference of realized costs and perceived costs is evidence of the poor perception that sustainable construction currently has in the construction industry.

The second barrier to sustainable construction, lack of experience, was previously identified and testing in Section 4. It was determined that lack of experience is a barrier to sustainable construction. The findings from the industrial application support these findings and enhance the understanding as to how perception affects a sustainable construction project. Through analysis of the industrial application on the UVU New Science Building, lack of experience was initially recognized as a hindrance to successful sustainable construction.

The lack of experience was evident in both the field engineer managing the construction, and in the subcontractors. The field engineer on the UVU New Science project did not have prior experience managing a LEED project. This was his first project seeking LEED certification and he was not a LEED Accredited Professional or Green Associate. Although he lacked previous experience, he was tasked with identifying all of the credits that the construction manager was responsible for obtaining, as well as the plan for how to obtain the credits, and ultimately LEED certification. His previous work experience included ten years in the construction management field working on various projects, to include residential, retail, commercial, industrial, and medical projects. Prior to his work experience, he had graduated with a bachelor's degree in Public Relations with a minor in Construction Management.

The field engineer had completed LEED training internal to Big-D Construction prior to starting the project in July and August of 2010. The training was not all-encompassing, but he did learn the basics, such as how to implement a checklist (for the required points) and a waste management plan. Even after the training, the field engineer stated that he was "really petrified at the beginning… but the more I got involved, the more I learned that it is not that big of a deal, just one more thing to track." The key to this understanding came from the field engineer's use of methodical processes that took unknown and seemingly complex requirements, and translated them into manageable pieces. This is what a construction manager is used to doing and has to do on every project.

In order to compensate and overcome his lack of experience with regards to LEED projects, the construction management company, Big-D Construction, had a senior project manager that oversaw the project on a limited basis. For any real issues or questions that the project manager had regarding LEED certification, he used reach back capabilities to the company's LEED subject matter expert. He also relied on the project architect. The field engineer communicated with the architect at least once a week. The field engineer rated the architect's availability at an eight out of ten and six out of ten on responsiveness. The field engineer believed that the architect "doesn't have time to do what he needs to do." When the field engineer needed more immediate assistance, he utilized Big-D's reach back capabilities to get the answer he needed regarding the LEED issues. When needed, the company LEED subject matter expert would visit the site, which the field engineer thought to be very helpful. The field engineer was then able to implement the instruction that he received and/or communicate it to the subcontractors on the project.

Current construction culture as a barrier to sustainable construction was previously identified and tested in Section 4. It was determined that current construction culture is a barrier to sustainable construction. The findings from the industrial application support these findings and enhance the understanding as to how construction culture affects a sustainable construction project. Despite the success of LEED and the U.S. Green Building movement in general, challenges abound when implementing sustainability principles within the well-entrenched traditional construction industry. Although proponents of green buildings have argues that whole-system thinking must underlie the design phase of this new class of buildings, conventional building design and procurement process are very difficult to change the within the mindset of the construction industry (Kibert, 2008).

The prevailing thinking towards LEED certification at the beginning of the project was that it was unnecessary, irrelevant, or redundant to the project specifications. The field engineer did not see the significance of obtaining LEED certification and the subcontractors viewed it as more unnecessary paperwork. When asked what he thought of the LEED requirements, the field engineer questioned the need for certification at all:

> *"Why do we need a certification system? Why can't [the requirements] be part of the specifications? Why can't we make [the requirements] part of best practices?"*

When asked how the subcontractors on the project viewed the LEED certification, he stated that,

> *"A lot of the subcontractors don't take it seriously. They think it is a political thing. Subcontractors don't like paperwork, let alone extra paperwork."*

6.1.1.1. Implementation of management methods. This section will detail the findings of this research as it relates to the methods, or construction management processes, that can overcome the barriers discussed in Section 4. Column one in Table 6.3 below lists the methods, while column two provides more detail on how the methods will specifically overcome the barriers:

Table 6.3 Methods to Overcome Barriers

Method to overcome barrier	**How the method overcomes barriers**
Early identification of sustainable requirements in the solicitation and specifications, and early documentation of LEED requirements	By requiring early identification of sustainable features in the bid, subcontractors will minimize any additional costs; documentation concurrent with construction will decrease.
Hold meetings that communicate expectations and progress to identify if expectations are met	Provide education in conjunction with experience and open communication in order to facilitate understanding of the project's sustainable requirements.
Checklists, inspections, coordination	Bridge the gap between new ideas and old ideas by translating new criteria into conventional methods of operating.

The methods listed about are broad in scope. In order for them to be implemented successfully during the construction of a project, they must be translated into a detailed plan that a construction manager can execute on order to successfully obtain the LEED credits that are the responsibility of the construction manager. The construction management methods to overcome the existing barriers to sustainable construction have been identified in this research as 1) Early identification of costs and requirements, 2) Documentation, 3) Communication, and 4) Standardization. In order for these methods to be successful, they need to be translated into definable steps that a construction manager can execute during the project. This breakdown of the methods into definable steps is what gives the construction manager a plan that he/she can execute in order to overcome the barriers. In this research, the definable steps have been organized according to the LEED requirements that the construction manager is responsible for. By organizing the methods into the LEED categories, the construction manager will be able to take requirements that are still perceived as difficult by those with misperceptions, unknown by those with a lack of experience, or disliked by the current construction culture, and turn them into a blue print on how to overcome these barriers.

Listed below, are the specific processes that a construction manager can implement during the field management of a project in order to successfully overcome barriers to sustainable construction, complete the project, and earn LEED certification. The purpose of the organization, or sub-categories, is to correlate the identified methods to the LEED credits that construction managers are responsible for on the project:

Construction Waste Management
a) Step 1: Establish a contract clause for waste management for each subcontractor
b) Step 2: Hold a pre-construction meeting to discuss and illustrate the waste management plan for the project
c) Step 3: Hold daily and monthly progress meetings and updates
d) Step 4: Collection of construction waste on the project site

Materials and Resources
e) Step 1: Bid breakout of materials
f) Step 2: Submittal process
g) Step 3: Record data and site verification

Indoor Air Quality
h) During construction coordination: HVAC system protection, Containment source control, Pathway interruption, Housekeeping, Scheduling
i) Before occupancy coordination: Flush out of the filtration system or Conduct an air test in accordance with the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air

Commissioning
j) Step 1: Establishment and communication
k) Step 2: Scheduling
l) Step 3: Implementation and coordination

6.1.1.1.1. Construction waste management. Step 1: Establish a contract clause for waste management for each subcontractor. The UVU New Science project specification defined construction waste in the specification as:

> *Building and site improvement materials and other solid waste resulting from construction, remodeling, renovation, or repair operations. Construction waste includes packaging and demolition.*

The project specification also dictated a salvage/recycling rate at 75% by weight of total non-hazardous waste generated by the construction work. The contractor was required to submit a waste management plan within 60 days of the start of construction.

The UVU project specification gave the subcontractors the option to have Big-D collect and sort their waste, or they could handle it themselves. The field engineer stated that this option was a poor specification because it created too many variables to manage, on a project that already had many moving pieces to coordinate. The only subcontractors that chose to remove its own waste were the sheet rock and roofing subcontractors. They in turn would give the waste tickets to the field engineer and he would add it into the overall project quantity tracker.

This is a typical situation of design-bid-build construction projects, where the owner typically has a contract with its prime contractor, but it is not passed on to the subcontractors. A clause in the contract regarding the expectations and requirements will keep the subcontractors fiscally accountable and will reduce any misunderstandings amongst the multiple subcontractors. The contract clause shall include the type of material to be collected, the duration for collection, and the method of collection. In essence, the contract clause will mirror the clause that the prime contractor has with the owner. This will eliminate the need for the field engineer to manage an additional variable into the tracking requirement. Instead of assimilating different tracking techniques, all waste will be tracked uniformly.

The field engineer stated that the less-experienced subcontractors overlooked the cost of waste removal and management in its bid. This was especially troublesome for the subcontractors that did not understand the LEED requirements. Subcontractors typically account of waste management in its overhead costs, but do not give much thought to the actually execution of a construction waste management plan. Compounding inexperienced subcontractors is the short time line in the bid process that does not allow the construction manager to coordinate with the subcontractor. As discussed in section in this section, the subcontractors only submit their bid to the construction manager less than 48 hours before the construction manager has to submit its bid to the owner. By establishing a contract clause between the construction manager and the subcontractors, there is an initial exposure to the requirement for waste management.

Step 2: Hold a pre-construction meeting to discuss and illustrate the waste management plan for the project. The waste management plan was submitted on August 26, 2010 from Big-D Construction to GSBS Architects for review and approval. The submittal detailed the construction manager's plan for managing all construction waste on site and obtaining LEED credit MR 2 Construction Waste Management at 75%, which would earn two points towards certification. The plan stated that:

> *These credits will be achieved when at least 75% of construction debris is salvaged and recycled in an effort to divert from landfills and incinerators. The project team has set the goal of diverting 95% of construction waste.*

A pre-construction meeting was held prior to mobilization and prior to the submission of the waste management plan. The pre-construction meeting consisted of a site walk and orientation which allowed the project management and subcontractors to visualize where the waste collection points would be located. Because the meeting was held on site, a site diagram was not needed. The field engineer stated that more detail should have been given, such as the diversion requirements and percentages.

Step 3: Hold daily and monthly progress meetings and updates. The project waste management plan also stated:

> *In addition, the general contractor will facilitate weekly project meetings with required attendance by all subcontractors. Part of the weekly agenda*

> *will be a section on the LEED aspects of the project. We will discuss current concerns, needs and processes for each trade to be aware of with regard to the LEED impacts on the project.*

In relation to waste management, the field engineer discussed the causes of waste and methods for improving waste management. In regards to this research, the causes and methods for improving waste management were first identified in Section 2. When asked to compare the studies of Glass and Cha, the field engineer identified which causes and methods applied to the UVU New Science Building, as seen below in Table 6.4. This information is important because this type of data should be discussed at the progress meetings.

Table 6.4 Causes of Waste Identified on UVU New Science Building

Origins of Waste (Osmani, 2007)	**Causes of Waste**	**Identified by UVU Project Manager**
Contractual	Errors in contract documents	X
Design	Design Changes	X
	Design and detailing complexity	X
	Design and construction detail errors	X
	Unclear/unsuitable specification	X
	Poor coordination and communication (late information, last minute client requirements, slow drawing revision and distribution)	X
Procurement	Ordering errors (i.e., ordering items not in compliance with specification	X
	Supplier error	X
Transportation	Damage during transportation	X
	Insufficient protection during unloading	X
	Inefficient methods of unloading	X
On-site Management and planning	Lack of on-site management plans	X
	Improper planning for required quantities	X
	Delays in passing information on types and sizes of materials and components to be used	X
	Lack of on-site material control	X
	Lack of supervision	X
Material storage	Inappropriate site storage space leading to damage or deterioration	X
	Improper storage methods	X
	Inadequate material handling	X
Site operation	Accidents due to negligence	X
	Unused materials and products	X
	Poor craftsmanship	X
	Use of wrong materials resulting in their disposal	X
	Poor work ethics	X
Residual	Waste from application process (i.e., over-preparation of mortar)	X
	Off-cuts from cutting materials to length	X
	Waste from cutting uneconomical shapes	X
	Packaging	X
Other	Vandalism	X

The field engineer also reviewed the list below of methods for improving waste management performance (Cha, 2009) and identifying the items that *should* be done and *were* actually done on the UVU project, as seen below in Table 6.5:

Table 6.5 Methods for Improving Waste Management Identified on UVU New Science Building

Category	Method	Should Do	Did on UVU
Manpower	Commitment of contractor's representative at site	X	X
	Appointment of laborers solely for wastes disposal	X	X
	Cooperation of subcontractors	X	X
	Education of the contractor's staff (engineers)	X	X
	Education of subcontractor's staff (laborers)	X	X
	Preventing waste of materials by laborers	X	X
Materials and Equipment	Collecting packed materials back by suppliers		
	Minimizing rework on a construction phase	X	X
	Design and construction using standardized materials	X	X
	Prefabrication of materials	X	X
	Use of recycled materials	X	X
	Prevent fragile materials from being used	X	X
	Minimizing loss of materials during carrying and storing	X	
Construction Method	Setting up separated bins by waste type	X	X
	Sorting individual waste by type from mixed wastes	X	X
	Designate a place for storing wastes in an early stage of construction	X	X
	Storing wastes at an easily accessible areas	X	X
	Preventing the ordering of excess materials	X	X
	Preventing mixing wastes with soil	X	X
	Installing an information board to notice categories for separating wastes	X	X
Management Practices	Contractual clauses for a subcontractor in dealing with wastes	X	X
	Positive incentive for decreasing or recycling by subcontractors	X	X
	Keeping a record about waste management	X	X
	Shortening a period of collecting wastes in a site	X	X
	Contractual clauses about the methods for a waste disposal agency to treat wastes		X
	Establishing a waste management plan in an early state of construction	X	X

The only methods that the field engineer did not find helpful are 1) collecting packed materials back by suppliers, 2) providing bins for collecting wastes for each subcontractor, 3) contractual clauses about the methods for a waste disposal agency to treat wastes, and 4) checklist on executing a detailed waste management plan. Considering the field engineer's lack of experience prior to this project, it is noteworthy that all of the methods that the he believed to be helpful were actually implemented on the project. By identifying the causes of waste, the field engineer was able to attempt to reduce the impact of the causes by addressing it with the subcontractors as part of the weekly agenda of the OAC meeting identified in the project waste management plan. There were little revisions to the initial waste management plan, so no updates were needed for materials to be collected, method of collection, location of bins, timing of collection, percent (%) of diversion, incentives, or points of contact.

Step 4: Collection of construction waste on the project site. Also identified in the waste management plan submittal was the company to handle construction waste management on site, Waste Management. This spreadsheet was managed by the field engineer. Waste Management provided further detail on the specific debris to be diverted and how the diversion percentages would be tracked. On projects with a small footprint, Waste Management offered the option of collection all waste in a single location; however, the UVU project had enough space to hold four dumpsters for collecting waste. Figures 6.1 through 6.4 below illustrate how the construction manager utilized the space to position the dumpsters in order to maximize the efficiency of waste collection.

Figure 6.1 Waste Collection (Photo 1)

Figure 6.2 Waste Collection (Photo 2)

Figure 6.3 Waste Collection (Photo 3)

Figure 6.4 Waste Collection (Photo 4)

The dumpsters were located towards the front of the construction site, so there was easy vehicular access to dumping. Figure 6.9 illustrates that there was enough space for a worker to dump its waste and the dumpsters were not obstructed. Big-D's goal of 95% diversion rate would earn the project an additional Innovation in Design point for exemplary performance. The plan stated the materials that would be collected and diverted, including but not limited to, concrete, metals, woods, plastic and cardboard. The plan specifically highlighted subcontractor participation as a vital component to the success of the plan:

> *Subcontractor participation is a vital element to achieving the success of this plan. A comprehensive pre-construction meeting will be held with all subcontractors prior to engaging work on the site. This process includes education with regard to the LEED goals of the project as well as general procedures for the project.*

The UVU project specification gave the subcontractors the option to have Big-D collect and sort their waste, or they could handle it themselves. The field engineer stated that this option was a poor specification because it created too many variables to manage, on a project that already had many moving pieces to coordinate. The only subcontractors that chose to remove its own waste were the sheet rock and roofing subcontractors. They in turn would give the waste tickets to the field engineer and he would add it into the overall project waste quantity tracker.

The field engineer state that "waste management is the part of LEED to me that is the most important." He felt that it was a positive facet in the LEED process to be able to remove waste for landfills and reuse it for other purposes. This is significant because it identifies an area where the construction management team took ownership and satisfaction in being part of the LEED process. This field engineer was able to overcome his initial fear of LEED by managing the process efficiently and effectively and seeing the overall positive benefits. He was also able to overcome the construction culture that views LEED as unnecessary because he found a part of the certification process that has a positive impact on the environment, but at the same time did not interfere with the production of the construction project.

6.1.1.1.2. Materials and resources. Step 1: Bid breakout of materials. The project specifications stated that the building materials shall have recycled content such that post-consumer recycled content plus one-half of pre-consumer recycled content for the project constitutes a minimum of 20 percent of the costs of materials used for the project. Not less than 10 percent of the building materials (by cost) shall be regional materials. Locally sourced materials must have been extracted, harvested and processed within a certain radius (USGBC defines with radius as 500 miles). The UVU New Science project specification held the same definition, and considered locally sourced materials within a 500 mile radius. The project also noted that “if only a fraction of a product or material is extracted/harvested/recovered/manufactured locally, then only that percentage (by weight) shall contribute to the regional value.”

Because of the nature of the bid process discussed in section 4.3.2.2 Bid Process, it becomes even more important that the subcontractors are made aware of the complex requirements as soon as possible because once the bid is accepted, there is no room to alter the accepted costs or schedule.

Step 2: Submittal process. Most of the submittals on the project were submitted early in the project, during foundation preparation and prior to vertical construction. The field engineer enforced his company’s policy of not allowing subcontractors to start work until the required submittals were turned in and approved. This was important because many of the smaller, less experienced subcontractors resisted doing any paperwork. Not allowing them to start work (and subsequently, get paid for their work) was incentive for them to turn in their submittals. The field engineer stated that the “submittals catch the issues before they become issues.” This was even more important with the added complexity of the LEED requirements that the subcontractors needed to adhere to.

The submittal process was also a form of education, or training, for the subcontractors because it forced them to do the necessary research in order to verify that the materials they would be procuring and utilizing, met the specifications. The field engineer stated that the project probably would not have received the Materials &

Resource credits had he not tracked the materials early on in the submittal process. The spreadsheet used to track and record the data was established during the submittal process.

Step 3: Record data and site verification. The field engineer recorded the material data on a spreadsheet that was initially created during the submittal process. The project engineer was able to use the spreadsheet to track recycled content, regional materials, and certified wood, which accounted for five LEED credits. He also maintained important documentation that verified that the project materials complied with the LEED requirements, such as Forest Stewardship Council chain-of-custody and VOC[28] data. The field engineer stated that he started tracking this data during the submittal process. He stated that the materials quantity was “not another process, but part of an existing process.” By making the materials tracking that was necessary for LEED certification a part of already-existing management processes, the field engineer was able to reduce the complexity and redundancy of additional paperwork.

The field engineer tracked the materials data incrementally throughout the job, starting during the submittal process. He stated that the project probably would not have achieved the points for certification if he had not incrementally tracked the data. Had he waited until the end of the job to compile the data, it would have been 1) too much work given a time constraint, and 2) left room for error and incomplete information.

[28] Volatile Organic Compound

6.1.1.1.3. Indoor environmental quality. The construction manager utilized a generic indoor air quality plan. The plan was adapted from a previous construction project. The plan stated that "during construction, there are several methods of controlling airborne contaminants and maintain a positive Indoor Air Quality." Table 6.6 below details the plan covered the following control methods.

Table 6.6 Indoor Air Quality Plan

Control Method	Specific Measures
HVAC Protection	All parts of the system shall be sealed during construction with plastic to prevent dust or other airborne contaminants from entering. It is the intent for the HVAC system to remain off during construction. If the system is operated during construction the following measures will be followed. Supply and return openings shall be covered with plastic if the system performance will not be greatly compromised. Otherwise, filtration media with a minimum efficiency rating value (MERV) of 13 shall be installed at the supply and return openings in the construction area. Mechanical Rooms shall not be used to materials.
Source Control	Use low VOC emitting: All materials containing VOCs including but not limited to carpets, adhesives, paints, caulks, cleaning solutions, wall coverings and furniture must comply with all LEED requirements. All Material Safety Data Sheets (MSDS) must be submitted and approved before materials enter the building. Equipment Operation: The use of propane or electric powered equipment in lieu of gasoline/diesel burning equipment when possible. Restrict equipment and on-site vehicle traffic where emissions could be drawn into the building. Cover or Seal: VOC emissions are a result of evaporation from an exposed surface. Containers of wet products should be kept closed as much as possible. Waste materials which can release odor or dust should be covered or sealed and removed from IAQ area.
Pathway Interruption	Building access shall be limited to designated locations to reduce and control contaminants entering the building. Create physical barriers around the work area to block airflow pathways to stop airborne contaminant transport. If weather permits, use 100% outside air to ventilate the contaminated area and depressurize the work area to ensure dust and vapors do not enter adjacent clean areas.
Housekeeping	Clean work areas daily to control contaminant accumulation. Use wetting agents or sweeping compounds to suppress dust during demolition and cleaning. Clean up spills as soon as they occur. Keep all surfaces where contaminants can collect clean. Protect porous materials from moisture. Provide a preliminary list of porous materials.
Scheduling	Materials should be scheduled to arrive just in time for installation. When material storage on site in necessary it is important to keep them clean and dry. Materials will be kept: Designated storage areas, Left in original packaging, Covered and raised off the floor, Inspected periodically. When VOC off gassing is a concern, performing the VOC producing activities at the end of the workweek to allow venting of the space over the weekend. Keep an up to date project schedule on site to ensure all work is complete prior to the building flush period.

The construction manager also documented its references for the plan: SMACNA[29] IAQ Guidelines for Occupied Buildings under Construction, Second Edition –November 2007, and US Green Building Council's LEED Reference Guide, Version 2.2. In order to ensure compliance with this LEED requirement (Indoor Environmental Quality 3.1 Construction IAQ Management Plan – During Construction), the field engineer would need to provide photographic evidence that the project was in compliance. The field engineer conducted regular inspections of the site to take photographs of the storage of materials, applicable signage, and storage of duct work. When the field engineer was unavailable to conduct the site visits, the field superintendent was responsible. The field superintendent was also responsible for ensuring compliance amongst the workers. The photos below illustrate the photographic documentation needed to submit for LEED certification that documented the project being in compliance with its Indoor Environmental Quality plan. Figure 6.5 illustrates implementation of the IEQ plan control method of scheduling (when material storage on site in necessary it is important to keep them clean and dry. Materials will be kept: Designated storage areas, left in original packaging, covered and raised off the floor, and inspected periodically) and housekeeping (Use wetting agents or sweeping compounds to suppress dust during demolition and cleaning:

[29] Sheet Metal and Air Condition Contractor's National Association

Figure 6.5 Indoor Air Quality Plan (Photos 1 & 2)

Figure 6.6 illustrates implementation of the IEQ plan control method of pathway interruption (if weather permits, use 100% outside air to ventilate the contaminated area and control contaminants entering the building):

Figure 6.6 Indoor Air Quality Plan (Photos 3 & 4)

Figure 6.7 illustrates implementation of the IEQ plan control method of HVAC protection (Supply and return openings shall be covered with plastic if the system performance will not be greatly compromised):

Figure 6.7 Indoor Air Quality Plan (Photos 5 & 6)

In order to get compliance to the Indoor Environmental Quality plan during construction, the field engineer relied on the submittal process detailed for Materials & Resources. The source control was made easier to enforce because the materials had their own MSDS (Material Safety Data Sheet), which are required to be posted on construction project sites and therefore already common and understood by the subcontractors. The field engineer inspected the project site every day and he stated that the subcontractors were typically in compliance with the requirements without even knowing it. Although this shows a lack of experience, or knowledge, it also illustrates how affective standardization of the project requirements can be. In the situation where a material was not in compliance with the project specifications, the field engineer would issue a warning to make the correction. He stated that one correction was typically enough to fix the problem; however if a subcontractor continued to use a noncompliant, or unknown material, it would be taken off the project site.

Before Occupancy. The field engineer was also responsible for the indoor air quality before occupancy (LEED credit 3.2 for indoor environmental quality) coordination. The LEED guidelines give two options for this credit: 1) Flush out of the filtration system or 2) Conduct an air test in accordance with the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air. The UVU specifications called for option 1, the flush out of the filtration system. The project specification required a "signed statement describing air flush-out procedures including the dates when flush-out was begun and completed and statement that filtration media was replaced after flush-out" as well as "product data for filtration media used during flush-out and during occupancy."

The field engineer was responsible for scheduling the flush out of the building in a time frame that met the end user's needs. The building flush out was scheduled to begin on March 12th, which was only four days before scheduled substantial completion (March 16th). The field engineer had to coordinate the planning and implementation with the mechanical engineer that would be conducting the flush out. The field engineer also had to coordinate with the end user of the building to ensure that it would be complete in time for building use. The end user accepted the substantial completion of the building without the flush out complete. The field engineer stated that had the end user required the flush out to be complete prior to substantial completion, he would have had to schedule the flush out to begin earlier. In order to make sure that the project schedule would be met and the building flush out would not delay turnover, the field engineer coordinated with the end user early in the project.

6.1.1.1.4. <u>Commissioning.</u> Step 1: Establishment and communication. The LEED Documentation for the UVU New Science Building required for commissioning credits included:

1. EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems
    a. Completed Owner's Project Requirements (OPR) and Basis of Design (BOD) documentation.
    b. Incorporated Commissioning requirements into construction documents.
    c. Developed and utilized a commissioning plan
    d. Verified installation and performance of commissioned systems.
    e. Completed Commissioning Report.
2. EA Credit 3: Enhanced Commissioning Verify the following:
    a. The CxA has conducted at least one Commissioning Design Review of the Owner's Project requirements (OPR), Basis of Design (BOD), and design documents prior to mid-construction documents phase and back-check the review comments following design submission.
    b. The CxA has reviewed contractor submittals applicable to systems being commissioned for compliance with the OPR and BOD.
    c. A systems manual that provides future operating staff the information needed to understand and optimally operate the commissioned systems has been prepared for the project.
    d. The operating personnel and building occupants have been trained in the operation and maintenance of the commissioned systems.
    e. The CxA will review building operation within 10 months after substantial completion, and a plan for resolution of outstanding issues has been completed.

The establishment of the commissioning requirements was part of the project specifications. It was the responsibility of the commissioning agent, hired by the owner, to take the specifications and craft a specific commissioning plan for the project. The field engineer ensured that the commissioning plan was feasible. Once this was accomplished, it was the responsibility of the field engineer to communicate the plan to the subcontractors. Approximately three weeks prior to the finalization of the commissioning plan, there was a commissioning kick-off meeting held (on December 14, 2010) that communicated all of the pertinent information about the commissioning plan to the project team, to include the subcontractors and owner. Holding the meeting prior to the finalization of the plan allowed the commissioning agent to field any questions or issues that might to be addressed in the final plan.

Step 2: Scheduling. The field engineer was responsible for the scheduling of all commissioning related activities. This required an additional level of coordination because the commissioning activities were established by the commissioning agent (as an employee of the owner), but implementation of those activities was done primarily by the building envelope, mechanical, and electrical subcontractors. Because of this extra level of complexity, the field engineer identified the need to get the commissioning activities incorporated into the schedule as soon as the initial commissioning plan was complete. The field engineer ran into difficulty accomplishing this task because the commissioning agent did not provide the necessary level of detail to satisfy all of the commissioning activities. For example, the commissioning agent did not notify the field engineer that he would need the building to be 100% complete with no construction activities ongoing in order to monitor the building's HVAC system. He required two weeks to monitor the building, but he only brought this to the attention of the field engineer one month before substantial completion. The schedule did not allow for two weeks to be given to the commissioning agent before substantial completion. Because of this turn of events, the commissioning agent felt ”short changed”, according to the field engineer; however the field engineer stated that it was his responsibility, not the commissioning agent's, to get the building completed on time.

In order to rectify the schedule bust created by poor planning and scheduling on the part of the commissioning agent, the field engineer was able to discuss the situation with the owner and the owner agreed to accept the building at substantial completion and have the HVAC system monitoring competed after substantial completion. The field engineer learned that even though he had asked for a detailed commissioning schedule from the commissioning agent, he should have been more adamant to avoid this type of situation.

Step 3: Implementation and coordination. Commissioning meetings were held weekly, every Tuesday, and the participants included the field engineer and superintendent, the key subcontractors that would play a role in commissioning (building envelope, mechanical, and electrical), the commissioning agent, and an owner's representative. As stated previously, the project owner directly hired the commissioning agent. The purpose of these meetings was to coordinate the ongoing commissioning activities and deconflict the construction activities with the necessary commissioning activities. It was in this weekly meeting that the scheduling issue for the two week HVAC monitoring was resolved.

The construction manager was not responsible for the actual commissioning of the building; the owner hired the commissioning agent directly. The commissioning agent was also directly responsible for uploading the required LEED documentation to

LEED Online[30]. The field engineer was responsible for providing all on-site startup reports by factory representatives and certificates of readiness for all systems, subsystems, equipment and associated controls. The field engineer is responsible for coordinating the site visits, inspections, and schedule of the all commissioning agent's activities. The project specifications detailed the construction manager's responsibilities as the following:

1. Participate in design- and construction-phase coordination meetings.
2. Integrate all commissioning activities into the master schedule.
3. Participate in maintenance orientation and inspection
4. Participate in operation and maintenance training sessions.
5. Certify that work is complete and systems are operational according to the contract documents, including calibration of instrumentation and controls.
6. Evaluate performance deficiencies identified in test reports and, in collaboration with entity responsible for system and equipment installation, recommend corrective action.
7. Review and approve final commissioning documentation
8. Participate in ten-month review as required by LEED

The construction manager is also responsible for ensuring that the subcontractors perform items one through eight listed above.

6.1.1.2. Industrial application summary. At the beginning of the project, the field engineer did not have experience, and therefore lacked confidence in his ability to achieve LEED certification. He stated that "there is no way I would have been able to do this job without people who have done it before." By the end of the job, the field engineer was actually helping others within his company with the LEED process. He also changed his perception from LEED being extra paperwork for certification to LEED as a "principle" that was actually beneficial to the environment.

---

[30] LEED Online is the website that each project utilizes to submit the credits to Green Building Council for review.

Table 6.7 below outlines the LEED credits that the construction manager was responsible for in order to achieve certification. Out of the 50 points necessary to reach the silver level, the construction manager was responsible for 17 points, or 34%.

Table 6.7 LEED Credits (Construction Management's Responsibility)

Credit	Possible Points
SS Prerequisite 1 Construction Activity Pollution Prevention	
EA Prerequisite 1 Fundamental Commissioning of Building Energy Systems	
EA 3 Enhanced Commissioning	2
MR 2 Construction Waste Management	2
MR 4 Recycled Content	2
MR 5 Regional Materials	2
MR 7 Certified Wood	1
IEQ 3.1 Construction IAQ Management Plan – During Construction	1
IEQ 3.2 Construction IAQ Management Plan – Before Occupancy	1
IEQ 4.1 Low-Emitting Materials – Adhesives and Sealants	1
IEQ 4.2 Low-Emitting Materials – Paints and Sealants	1
IEQ 4.3 Low-Emitting Materials – Flooring Systems	1
IEQ 4.4 Low-Emitting Materials – Composite Wood and Agrifiber Products	1

LEED certification was achieved at the targeted level of silver. All targeted construction management credits were achieved for construction waste management, materials and resources, indoor air quality, and commissioning.

Table 6.8 summarizes the existing barriers to sustainable construction that were identified in this research, as well as the construction management methods that can overcome the barriers with the corresponding implementation of the methods.

Table 6.8 Overcoming Barriers with Implementation of Management Methods

Barrier	**Construction Management Method to Overcome Barrier**	**Implementation of Construction Management Methods**
Perception	1) Hold meetings that communicate expectations and progress to identify if expectations are met; 2) project inspections – provide education in conjunction with experience and open communication in order to facilitate understanding of the project's sustainable requirements.	*Construction Waste Management*: establish a contract clause for each subcontractor, hold a pre-construction meeting to include waste management plan, hold daily/monthly progress meeting and updates, and collection of waste on project site *Materials & Resources*: bid breakout of materials, submittal process, record data and site verification *Indoor Air Quality*: during construction and before occupancy coordination *Commissioning*: establishment and communication, scheduling, and implementation and coordination
Lack of experience	Hold meetings that communicate expectations and progress to identify if expectations are met – provide education in conjunction with experience and open communication in order to facilitate understanding of the project's sustainable requirements.	
Current construction culture	Checklists, inspections, coordination – bridge the gap between new ideas and old ideas by translating new criteria into conventional methods of operating.	

7. CONCLUSION

This research identified the importance and prevalence of sustainable construction in the overall construction industry; but in spite of the growing significance of this aspect of construction, barriers still plague the industry with regards to sustainable endeavors and LEED certification. These barriers continue to prevent government buildings from a timely closeout and turnover and they prevent private sector developers from pursuing sustainable construction.

As first stated in Section 1, the goal of this research is to provide answers to how to implement successful process on a sustainable construction project and achieve LEED certification, while overcoming the existing barriers to sustainable construction. This research was able to achieve this goal through testing of results from a survey, focus group, and an industrial application. These three approaches provided a way to incorporate both a broad and in-depth look at how the construction management processes presented in this research can contribute to the successful management of sustainable construction. In addition to the goal of this research identified in Section 1, this research also highlighted five key objectives needed to achieve this goal. These five objectives were highlighted because they account for the LEED credits that the construction manager is responsible and the cumulative effect of these objectives leads to the successful completion of a sustainable project by overcoming the existing barriers. While it is the cumulative effect of all the construction management processes presented in this research, some management processes have a greater effect on certain barriers.

These objectives are listed below, along with a summary of how this research demonstrated their usefulness in overcoming the barriers:

i) Identify any remaining barriers to sustainable construction: The barriers to sustainable construction were identified by conducting a focus group and gathering and analyzing the results. It was determined that the existing barriers are 1) poor perception triggered by bad experience, 2) lack of experience, and 3) prevalence of conventional thinking.

ii) Identify a process for management of a sustainable construction project consisting of construction waste management, materials and resources, indoor air quality, and commissioning: the construction management process was evaluated on an industrial application, proving that the method can lead to successful completion and LEED certification of a project.

(1) The need for a management process to address waste diversion on a sustainable project was identified through a survey. The method to manage waste diversion from the project site was evaluated with an in-depth analysis of a project (industrial application). It was determined that the construction waste management process of establishing a contract clause for each subcontractor, hold a preconstruction meeting with waste management plan included, hold daily/monthly progress meetings with waste management included, and collection of waste on site presented in this study was effective in overcoming the barriers of perception, lack of experience and conventional thinking. The four-step process encompasses

documentation, early identification of costs and requirements in the bid, communication during the project, and standardization.

(2) The need for a management process to address material and resource management was identified through a survey. The method to manage materials was evaluated with an in-depth analysis of a project (industrial application). It was determined that the materials and resources management process of bid breakout of materials, submittal process, and record data and site verification presented in this study was effective in overcoming the barriers of perception and lack of experience. This three-step process is most useful as a means of documentation and early identification of costs and requirements in the bid.

(3) The need for a management process to address indoor air quality was identified through a survey. The method to manage indoor air quality was evaluated with an in-depth analysis of a project (industrial application). It was determined that the indoor air quality management process of coordination during construction and before occupancy presented in this study was effective in overcoming the barrier of perception because it is most useful as a means of documentation.

(4) The method to manage commissioning was evaluated with an in-depth analysis of a project (industrial application). It was determined that the commissioning management process of establishment and communication, scheduling, and implementation and coordination presented in this study

was effective in overcoming the barrier of conventional thinking because it is most useful as a means of communication during the project.

The construction management processes that I developed in this research are significant because a LEED construction project was successfully completed using my method with no increase to cost, time, or at the expense of quality. Construction was scheduled to be finished in March 2012 and it was actually completed on time and turned over to the owner in March 2012.[31] The project was awarded at $32 million (including $2 million of owner changes), and it was completed for $32 million. The quality of the project and the management of the project were commended by the end user. In fact the owner's representative stated that he believed that "LEED would be harder for [the project manager] to track", but that he believed the project was "very well run" and "very organized." He did not notice any quality issues and was pleased with the contractor's performance.

The construction management process developed in this research also filled the holes in the current guidance for obtaining LEED certification, that were first identified in Section 1. This construction management process developed in this research gives a project manager the steps he or she needs to successfully complete a LEED project. Table 7.1 below details what the current guidance and the holes that need to be filled, as well as how the method developed in this research fills the holes and gives a project manager what he or she needs to successfully compete a project.

---

[31] This is significant as compared to U.S. Corps of Engineers projects which have 49% over cost and 46% over time (Resident Management System accessed 26 June 2014).

Table 7.1 Summary Chart of Research

Current Practices	**What are the holes in the current practices**		**How my method fills the hole**	**Implementation of my method on a case study (Industrial Application)**
Construction waste management				
What does LEED and literature say?	**What is missing?**	**Source that identifies the hole?**	My method specifically lists details as to how the construction manager interacts and communicates with the subcontractors. My plan also details how to make waste management effective it terms of meeting the LEED requirements, removing waste from site, and overcoming the barriers to sustainable construction previously identified in this research. My method specifically states that the designated person for construction waste management is the construction manager and provides detail as to what he/she should do to educate the subcontractors on the issues, policies, and procedures regarding waste management and LEED criteria. Through a four-step process, the construction manager can effectively and efficiently ensure that the project delivery team is able to meet all waste management criteria.	The case study implemented the four steps identified in this research in regards to waste management. Step 1: establish a clause for each contractor, Step 2: hold a pre-construction meeting to discuss and illustrate the waste management plan for the project, Step 3: Hold daily and monthly progress meetings and updates, and Step 4: Collection of construciton waste on the project site) were implemented and led the field engineer to the conclusion that waste management was the most important part of LEED certification because of the diversion of waste from landfills.
Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and whether the	There is no mention of the construction manager's interaction with the subcontractors. There is no	1. Survey question "Would a standardized process for waste collection on a project site be helpful?", 2. Literature review (Haselbach, 2008)		
A detailed and comprehensive plan is important to the success of the construction project. There is a need to optimize construction practices to facilitate construction	The need for a detailed plan is highlighted without mentioning what the details of the plan actually are.			
A properly conceived waste management plan allows a contractor to choose economical alternatives in project waste management. Construction and demolition wastes	The need for a properly conceived waste management plan is highlighted without mentioning what the plan			
When no one is designated to manage waste, the project team would be less keen to discuss waste management during their project meeting, or make their subcontractors aware of any waste policies (Ilozor, 2009).	The need for a designated person to manage waste is highlighted without mentioned what that person should do to make the subcontractors aware of any issues, policies, or procedures regarding waste management.			

Current Practices	**What are the holes in the current practices**		**How my method fills the hole**	**Implementation of my method on a case study (Industrial Application)**
		Materials and resources		
What does LEED and Literature say?	**What is missing?**	**Source that identifies the hole?**		
Keep a record and prepare documentation for building reuse, reused or salvaged materials, recycled content (product names, manufacturers' names, costs, percentage postconsumer content, and percentage preconsumer content), regional materials (distances between the project and manufacturer and distance between project and extraction site), rapidly renewable products, and chain-of-custody documentation (Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction).	There is only a list of data that needs to be recorded. There is no mention of how to procure or install the materials. There is also no mention of how to ensure compliance with the subcontractors actually utilizing the materials.	1. Survey question "Would it be helpful to require subcontractors to itemize their materials with regards to LEED criteria in their bid?"	My method details how the construction manager can educate the subcontractors as to what is required in accordance with the project specification and to meet the LEED criteria. The method also details how to acquire the information needed from the subcontractors and how to effectively monitor installation of materials on the project site. Through a three-step process, the construction manager can effectively and efficiently ensure that the project delivery team is able to meet all material and resource requirements needed to achieve LEED criteria.	The case study implemented Step 1: bid breakout of materials was not implemented because the project was a design-bid build and the bid was complete prior implementation of my method. Step 2: submittal process and Step 3: record data and site verification were implemented and led the field engineer to the conclusion that "the more I got involved, the more I learned that it is not that big of a deal, just one more thing to track." My method was also applicable and successful because it took unknown and difficult criteria and translated it into something understandable, as evidenced by the field engineer's statement that it was "not another process, part of an existing process." Now th efield engineer is assisting other in his company on LEED project.
Improper on-site management and planning can cause delays in passing information on types and sizes of materials and components to be used on the project	There is no information given regarding detail on what proper on-site management is.			
All materials are identified as construction submittals; therefore it is the responsibility of the construction manager to ensure that the submittals are timely and in accordance with the LEED criteria for point acceptance (Haselbach, 2009).	There is no mention of how the construction manager should get the submittals from the subcontractors and document how it meets LEED criteria, in a timely manner.			

Current Practices	What are the holes in the current practices		How my method fills the hole	Implementation of my method on a case study (Industrial Application)
Indoor air quality				
What does LEED and literature say?	**What is missing?**	**Source that identifies the hole?**		
Meet the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.12007, Ventilation for Acceptable Indoor Air Quality, prohibit smoking in the	This is only a list of standards to follow with regard to air ventilation criteria. There is no mention of how	1. Survey question "If you do not have a checklist that is used for IAQ (indoor air quality) inspections, would a checklist be helpful?"	My method explains how to incorporate the ASHRAE standards into the subcontractor's work and subsequently how to document how the project met the LEED criteria. The construction manager's procedure consists of two steps which include creating and implementing a thorough plan and communicating it to all applicable subcontractors during construction (step one) and prior to occupancy (step two).	The case study implemented both steps identified in this research (Step 1: during construction coordination and Step 2: before occupancy). Implementation of these steps led the field engineer to the conclusion that "the more I got involved, the more I learned that it is not that big of a deal, just one more thing to track." My method was also applicable and successful because it took unknown and difficult criteria and translated it into something understandable, as evidenced by the field engineer's statement that it was "not another process, part of an existing process." Now the field engineer is assisting other in his company on LEED project.
The nature of air inside the space that affects the health and well-being of building occupants (Haselbach, 2008).	There is no mention of how to manage the project requirements, only a description of what indoor air			
Construction process include methods for storing materials to prevent the introduction of moisture or the accumulation of dust, particulate, and other contamination or nonporous surfaces such as ductwork (Kibert, 2008).	There is no mention of how to mange the subcontractors to meet the criteria or what methods to utilize; it only states that materials should be stored and gives an example of what kind of material should be stored (ductwork).			

Current Practices	**What are the holes in the current practices**		**How my method fills the hole**	**Implementation of my method on a case study (Industrial Application)**
		Commissioning		
What does LEED and literature say?	**What is missing?**	**Source that identifies the hole?**		
Designate an individual as the commissioning authority (CxA) to lead, review, and oversee the completion of the commissioning process activities. The CxA must	There is no mention of the construction manager, only the commissioning authority (who has no	1. Literature review (Commissioning for Better Buildings in Oregon, 1997; Elzarka, 2009)	My method clearly explains how the construction manager is the main party responsible for the commissioning efforts on the project. It also explains how the construction manager can coordinate the efforts of the commissioning authority, the owner, and the subcontractors and incorporate the objects of all parties involved to successfully commission the project and meet the LEED criteria. The construction manager's procedure for both preconstruction and during consists of three steps which include establishing a commissioning plan and distributing to all necessary parties, scheduling of the commissioning activities into the project schedule, and supervision and implementation to maximize efficiency of	The case study implemented all three steps identified in this research (Step 1: estalishment and communication, Step 2: scheduling, and Step 3: implemtation and coordination. Implementation of these steps led the field engineer to the conclusion that "the more I got involved, the more I learned that it is not that big of a deal, just one more thing to track." My method was also applicable and successful because it took unknown and difficult criteria and translated it into something understandable, as evidenced by the field engineer's statement that it was "not another process, part of an existing process." Now th efield engineer is assisting other in his company on LEED project.
During the construction phase the commissioning team works to ensure that equipment, systems and assemblies are properly installed, integrated, and operating in a manner that meets the Owner's project Requirements (New Construction Building Commissioning Best Practices: Building Commissioning Association, 2011).	This is a general overview of what commissioning is; it does not provide any mention of how the construction manager plays a role in the commissioning process.			
General contractors, provided they have experience with projects of similar size and complexity, have the scheduling and construction background necessary to supervise a commissioning agent in the quality control manager sense. The general contractor assists with the development and implementation of functional performance testing for all systems. This involves assisting in gathering information (shop drawings, operation and maintenance manuals, and as-built documents) for review by the project team. The general contractor facilitates the commissioning schedule by coordinating activities with owner representatives and subcontractors. Contractors and subcontractors are also responsible for training building operators in the proper operation and maintenance manuals on the equipment that they install (Commissioning for Better Buildings in Oregon, 1997).	There is no mention of how the construction manager should coordinate between the different entities, such as the commissioning agent and the subcontractors. This reference only states that the construction manager is responsible for coordination without mentioning how to do it.			

These findings are significant to the construction industry because of the potential in reductions of inefficiencies associated with untimely building turnover and/or rejection of LEED credits by the Green Building Council. If the barriers are not overcome, extra costs and untimely turnover of the building to the owner/end user will continue and perpetuate the barriers of poor perception and prevalence of conventional thinking. Cost driven by poor perception was identified from the focus group and captured in the statements; "Still a huge amount of resistance. Green doesn't pay, green is too expensive. Still a lot of misconceptions", and "A lot of owners still think it is a costly endeavor, not necessary." Untimely building turnover and/or rejection of LEED credits was also identified in the focus group and captured in the statement, "They hear stories from people throughout the industry. You submit all your points to USGBC. And they come back with petty little things to dispute it and there is a cost and it puts a bad taste in folks mouth because it is obvious that the effort is there but there is this entity that says, if you want to argue with me it's $500 (per dispute)."

These findings are significant to academia because professors can use the management methods proposed in this research to prepare students of engineering management, construction management, and sustainable construction as project engineers or construction managers. As evidenced by the field engineer, experience or understanding prior to a project commencing is helpful to alleviate on-the-job training, or trying to cram in training prior to the start of the project. In addition to the teaching aspect of academia, these findings can be used in further research as well. Future research can use the barriers and management practices identified in this research to quantify the cost and lack of productivity from each barrier to construction and the cost of each management method, if not followed.

These findings also impact the industry because the graduates entering the construction field are vitally important to the successful completion of construction projects. Not only do novice project engineers execute important tasks necessary to the successful completion of construction, but they also provide construction management companies with a basis for the latest practices and technologies because they are only recently removed from academia. In addition to new professionals entering the construction industry, this research can be helpful to on-going projects and planning for future projects. For example, the U.S. Corps of Engineers is currently developing an Engineer Regulation for sustainable construction management practices.

There are many future research topics that can expound on the research presented in this study. Several important topics include 1) incentivizing LEED construction for developers, 2) the human element of construction management to include the more subjective management methods and results, 3) comparison of the different sustainable certifications, 4) quantifying the economic cost of the barriers, 5) the LEED certification process upon project completion and credit submission and 6) more case studies on differing types of construction to include residential and commercial.

BIBLIOGRAPHY

Abidin, Nazirah Zainul, Pasquire, Christine L. "Delivering Sustainability through Value Management," Engineering, Construction and Architectural Management, Vol, 12, No. 2, 2005, pp. 168-180.

Basili, V., Caldiera, G., and Rombach, H.D. Goal Question Metric Approach, Encyclopedia of Software Engineering, pp. 528-532, John Wiley & Sons, Inc., 1994.

Beatty, MaryAnne (October, 28, 2010). *GSA Moves to LEED Gold for All New Federal Buildings and Major Renovations*. Retrieved from http://www.gsa.gov/portal/content/197325.

Bhattacharyya, Gouri K., and Johnson, Richard A. Statistical Concepts and Methods. Wiley & Sons, New York, 1977.

Blacud, Nicolas A., Bogus, Susan M., Diekmann, James E., Molenaar, Keith R. "Sensitivity of Construction Activities under Design Uncertainty," Journal of Construction Engineering and Management, Vol. 135, No. 3, 2009, 199-206.

Commissioning for Better Buildings in Oregon. Oregon Office of Energy, March 1997.

Burr, Kevin. "Construction Delivery Methods" Lecture for Construction & Building Managers, Brigham Young University, 2011.

Button, Charles E. "Towards Carbon Neutrality and Environmental Sustainability at CCSU," International Journal of Sustainability in Higher Education, Vol 10 No. 3, 2003 pp. 279-286.

Cha, Hee Sung, Kim, Jeehye, Han, Ju-Yeoun. "Identifying and Assessing Influence Factors on Improving Waste Management Performance for Building Construction Projects," Journal of Construction Engineering and Management, Vol, 135, No. 7, 2009, pp.647-656.

Dawes, John, "Do Data Characteristics Change According to the Number of Scale Points Used? An Experiment using 5 Point, 7 Point and 10 Point Scales," International Journal of Market Research, Vol 51, no. 1, 2008.

DPR Construction. Accessed July 3, 2013.http://www.DPR.com.

Elzarka, Hazem M. "Best Practices for Procuring Commissioning Services," Journal of Management in Engineering July 2009, pp. 155-164.

Essa, Ranya, Forune, Chris. “Pre-Construction Evaluation Practices of Sustainable Housing Project in the UK,” Engineering, Construction and Architectural Management, Vol. 15, No. 6, 2008, pp. 514-526.

Frank, Thomas. “Green Schools?: Long on Promise, Short on Delivery.” *USA Today* 11 December 2012: Print.

Galayda, Jaimie (April 2010). Green Building Trends in Higher Education. Retrieved from www.greenbuildconsult.com.

Glass, Jacqueline. “Architects’ Perspectives on Construction Waste Reduction by Design,” Waste Management, pp.1147-1158, Vol. 28, No. 7, December 2008.

Grantham, Katie, Okudan, Gul, Simpson, Timothy, Ashour, Omar. “A Study on Situated Cognition: Product Dissection’s Effect on Redesign Activities,” 2010 ASME Design Engineering Technical Conferences – Design Education Conference, August 15-18, 2010, Montreal, Quebec, Canada, ASME, Paper No. DETC2010/DEC-28334.

Green Building Design and Construction: LEED Reference Guide for Green Building Design and Construction. U.S. Green Building Council (USGBC), 2009.

Hale, Darren R., Shrestha, Pramen P., Gibson, Edward, Migliaccio, Giovanni. “Empirical Comparision of Design/Build and Design/Bid/Build Project Delivery Methods,” Journal of Construction and Engineering, pp. 579-587, Vol, 135, No. 7, July 2009.

Hallowell, Matthew, Toole, T. Michael. “Contemporary Design-Bid-Build Model,” Journal of Construction Engineering and Management, pp. 540-549, Vol. 135, No. 6, June 2009.

Hartmann, Andreas, Caeteling, Jasper. “Subcontractor Procurement in Construction: the Interplay of Price and Trust,” Supply Chain Management: An International Journal, pp. 354-362, Vol. 15 No. 5, 2010.

Haselbach, Liv. *The Engineering Guide to LEED-New Construction; Sustainable Construction for Engineers*. McGraw Hill: New York (2008).

Hwang, Bon-Gang, Yeo, Zong Bao. “Perception on Benefits of Construction Waste Management in the Singapore Construction Industry,” Engineering, Construction, and Architectural Management, Vol. 18, No. 4, 2011, pp. 394-406.

Ilozor, Ben Dozie. “Differential Managemetn of Waste by Construction Sectors: A Case Study in Michigan, USA,” Construction Management and Economics, pp.763-770, Vol 27, August 2009.

Kibert, Charles J. Sustainable Construction; Green Building Design and Delivery, 2nd Ed., John Wiley & Sons Inc., New Jersey, 2008.

King, Jason. “Software Solutions for Obtaining a Kappa-Type Statistic for Use with Multiple Raters,” Educational Research Association, Dallas, Texas, February 5-7, 2004.

Krueger, Richard A. “Systematic Analysis Process” Accessed July 3, 2013. http://www.tc.umn.edu/~rkruger/focus _analysis.html.

Lam, Edmong W.M., Chan, Albert P.C., Chan, Daniel W.M., “Determinants of Successful Design-Build Projects,” Journal of Construction Engineering and Management, pp.333-341, Vol. 134, No. 5.

Lavy, Sarel, Fernandez-Solis, Jose L. “LEED Accredited Professionals’ Perceptions Affecting Credit Point Adoption,” Facilities, Vol. 27 No. 23/14, 2009, pp. 531-548.

Liamputtong, Pranee. *Focus Group Methodology: Principle and Practice*. London: SAGE Publications Ltd 2011.

Matthiessen, Lisa, Morris, Peter. Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adaption, 2007.

Makin, Linda. UVU Phase I-Case for Action and Array of Strategies and Tools. March 31, 2011.

McWhirt, Darren, Ahn, Junyong, Shane, Jennifer S., Strong, Kelly C., “Military Construction Projects: Comparison of Project Delivery Methods,” Journal of Facilities Management, Vol.9, no. 3, pp.157-169, 2011.

Merriam, S.B. Qualitative Research and Case Study Applications in Education. San Fransisco, CA; Jossey-Bass Publishers. 2002.

Mills, Thomas H., Showalter, Eric, Jarman, David. A Cost-Effective Waste Management Plan, Cost Engineering, Mar 1999 pp.35-43, Vol. 41, No. 3.

Minchin, Edward R., Henriquez, Nicholas, R., King, Aaron M., Lewis, Don W., “Owners Respond: Preferences for Task Performance, Delivery Systems, and Quality Management,” Journal of Construction Engineering Management, pp. 283-293, Vol. 136, No. 3, March 2010.

Mitchell, Adrian, Frame, Ian, Coday, Alan, Hoxley, Mike. “A Conceptual Framework of the Interface between the Design and Construction Processes,” Engineering, Construction and Architectural Management, Vol. 18 No. 3, 2011, pp. 297-311.

Morris, Peter. "What Does Green Really Cost," The Green Issue Feature, PREA Quarterly, Summer 2007, pp. 55-60.

Napier, Thomas R., Stumpf, Annette L., Schneider, Richard L., Hunter, Samuel L., Jenicek, Elisabeth M., Chu, Dahtzen. The Value of "Green to the Army Construction Engineering Research Laboratory, March 2011.

New Construction Building Commissioning Best Practice: Building Commissioning Association, December 8, 2011. Accessed January 15, 2012. http://bcxa.org.

Oberlander, Garold. Project Management for Engineering and Construction, 2nd Ed., McGraw Hill, Boston, 2000.

Passmore, Cindy, Dobbie, Alison E., Parchman, Michael, Tysinger, James. "Guidelines for Constructing a Survey," Family Medicine, Vol. 34, No. 4, 2002, pp.281-286.

Pitt, Michael, Tucker, Matthew, Riley, Mike, and Longden, Jennifer. "Towards Sustainable Construction: Promotion and Best Practices," Construction Innovation, Vol. 9 No. 2, 2009, pp. 201-224.

Potbhare, Varun, Syal, Matt, Arif, Mohammed, Khalfan, Malik M.A., Egbu, Charles. "Emergence of Green Building Guidelines in Developed Countries and their Impact on India," Journal of Engineering, Design and Technology, Vol. 7, No. 1, 2009, pp. 99-121.

Presley, Adrien, Meade, Laura. "Benchmarking for Sustainability: an Application to the Sustainable Construction Industry," Benchmarking: An International Journal, Vol. 17, No. 3, 2010, pp. 435-451.

Reed, Bill G. The Integrative Design Guide to Green Building. John wiley & Sons, Inc., New Jersey, 2009.

Ried, Robin C. "Using LEED as a Resource for Campus Sustainability Planning: A White Paper." University of California, Berkeley, 2008.

Robichaud, Lauren Bradley and Anantatmula, Vittal S. "Greening Project Management Practices for Sustainable Construction," Journal of Management in Engineering Jan 2011, Vol 27, No.1.

Robinson, Herbert S., Carrillo, Patricia M., Anumba, Chimay J., Al-Ghassani, Ahmed M. "Knowledge Management Practices in Large Construction Organisations," Engineering, Construction and Architectural Management, Vol 12, No.5, 2005, pp. 431-445.

Roulo, Candace (December 2, 2009). *Federal buildings to achieve zero-net energy by 2030*. Retrieved from http://contractormag.com/news/federal-buildings-net-zero-1209/.

Simon, Judith Sharken (1999). *How to Conduct a Focus Group*. Retrieved from http://tgci.com.

Stake, R.E. (1998) "Case Studies." In Strategies of Qualitative Inquiry, ed. Norman K. Denzin and Yvonna S. Lincoln, 86-108. London: Sage Publications.

Turner, Cathy, and Frankel, Mark. "Energy Performance of LEED for New Construction Buildings, Final Report." Washington: New Buildings Institute, 2008.

Yuan, Hongping, Shen, Liyin. "Major Obstacles to Improving the Performance of Waste Management in China's Construction Industry," Facilities, Vol. 29, No. 5/6, 2011, pp. 224-242.

Yudelson, Jerry. *Green Building A to Z; Understanding the Language of Green Building*. Canada: New Society Publishers, 2007.

Yudelson, Jerry. *Green Building through Integrated Design*. New York: McGraw Hill, 2009.

U.S. Green Building Council. Accessed 1 October 2013. http://www.usgbc.org/.

VITA

Cristin Colleen Szydlik was born in Philadelphia, PA. In June 2001, she received her B.S. in Economics from the United States Military Academy at West Point. She was commissioned as a Second Lieutenant in the U.S. Army. She deployed in support of Operation Iraqi Freedom in 2003 and Operation Enduring Freedom in 2005. In May 2005, she received her M.S. in Engineering Management from Missouri University of Science and Technology. After she completed her service in the Army, she continued to work in the construction field, both government and private sector. She returned to Missouri S&T in 2009 to complete her studies. She received her PhD in Engineering Management in August 2014.